BRUKER AXS HANDHELD

TRACER III-V Portable XRF Analyzer

Canadian User Manual

July 2008

415 North Quay• Kennewick, WA 99336
509-783-9850

Caution: X-ray Radiation

> ***► Note***
> Most countries and states regulate the use of X-ray generating devices such as XRF analyzers. Regulations for XRF analyzers vary by location. Contact your appropriate agency for specific information.

Bruker AXS Handheld manufactures an XRF analyzer designated as the Bruker TRACER III-V that contains an X-ray tube. It is registered with the U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health. Specific safety requirements are provided for any purchased analyzer which uses an X-ray tube.

The Bruker TRACER III-V contains an X-ray tube. The TRACER III-V does not emit radiation when turned off. It is designed with fail-safe circuitry including switches, lights, and interlocks to minimize the risk of accidental exposure to the user during operation.

The safety features of the TRACER III-V have been verified by radiation safety authorities. So long as there is no physical damage to the instrument, there should be no danger of exposure to radiation above permissible levels. If the instrument is damaged, store it in a secured area and contact Bruker AXS Handheld at (800) 466-5323.

> ***► Note***
> Countries or states may require registration and/or licensing. A fee payment may be required. If you are planning to transport a Bruker XRF analyzer into another location, contact the appropriate authority in that jurisdiction for their particular requirements before transporting the analyzer.

All XRF analyzers should be operated only by individuals who have completed an approved radiation safety training program.

The red LED on the analyzer indicates that the X-rays are on. Do not point the analyzer at any person when the analyzer is activated. While measuring, make sure that the analyzer is in contact with the sample material and that the entire aperture, as well as the infrared (IR) sensor, is covered by the material. While measuring, do not hold the sample material with your hand. Keep your eyes away from the nosepiece of the TRACER III-V while the trigger is pulled

In Canada, users must be certified in accordance with NRC Standard CAN/CGSB-48.9712-2000.

Note: Bruker TRACER III-V, Bruker XRF, and TRACER III-V, as used throughout this manual, refer specifically to the device manufactured by Bruker AXS Handheld.

Important Notes to Canadian Handheld XRF Analyzer Customers

The Bruker TRACER III-V is classified as a portable hand-held open-beam x-ray tube based analytical x-ray device, and as such Canadian Federal Regulations (Radiation Emitting Device Act) requires that **all Canadian users must be certified in accordance with NRC Standard CAN/CGSB-48.9712-2000.**

For user certification: contact, Natural Resources Canada, Manager Nondestructive Testing Certification, CANMET 586 Booth St. Ottawa, ON, K1A 0G1; Telephone: (613) 943-0583; FAX: (613) 943-8297.

Users are advised to contact their appropriate Federal/Provincial/Territorial radiation protection agency for applicable rules of operation.

This Bruker TRACER III-V User Manual provides training for Bruker TRACER III-V XRF analyzers. This manual contains four main sections and Appendix A that provides important information on the safe use of this XRF device. These are:

2. TRACER III-V Operator Radiation Safety Requirements
3. Principal Components of the TRACER III-V
4. Preparing the TRACER III-V for Use
5. Daily Operation

Appendix A Basic Radiation Safety

Section 2. contains operator safety requirements specific to the Bruker TRACER III-V and Appendix A contains basic radiation safety information.

Responsibilities of the Customer

- Before using the TRACER III-V, all users shall read and understand the Operator Radiation Safety Requirements (Section 2) and Basic Radiation Safety (Appendix A) of this manual. Because the TRACER III-V produces X-ray radiation, the instrument shall only be used by trained personnel who have passed the Bruker AXS Handheld Radiation Safety Examination.

- **Damage to a Bruker AXS Handheld analyzer may cause unnecessary radiation exposure.** If a Bruker XRF analyzer is damaged, immediately contact Bruker AXS Handheld at (800) 466-5323 or (509) 783-9850.

- **Disassembly of or tampering with any Bruker AXS Handheld XRF analyzer component, except to replace the batteries or remove the handheld computer (PDA), voids the warranty and compromises the integrity of the instrument. Harm or serious injury may result in cases where disassembly or tampering has occurred.**

- Comply with all instructions and labels provided with the TRACER III-V and do not remove labels. **Removal of any label will void the warranty**.

- Test the TRACER III-V for correct operation of the ON/OFF mechanism every six months and keep records of the test results. If the instrument fails this test, call Bruker AXS Handheld immediately for instructions.

- Maintain a record of TRACER III-V use, installation (if applicable), and any service to shielding and/or containment mechanisms for two years or until ownership of the instrument is transferred or the instrument is decommissioned.

- Report to the appropriate authority any possible damage to shielding and any loss or theft of the instrument. Do not abandon any XRF instrument.

- Transfer the TRACER III-V only to persons specifically authorized to receive it and report any transfer to the appropriate regulatory authority 15 to 30 days following the transfer, if required. Report the transfer of the instrument to Bruker AXS Handheld at (800) 466-5323 or (509) 783-9850.

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1. TRACER III-V Overview

The TRACER III-V, produced by Bruker AXS Handheld, is a portable, wide range elemental analyzer intended primarily for metal alloy analysis applications. It provides a method for chemical analysis or material identification (sorting) directly from materials of various forms. The TRACER III-V is based on energy dispersive X-ray fluorescence technology and uses an X-ray tube as its excitation source. Tubes may use a bulk Rhenium (Re), Rhodium (Rh) or Silver (Ag) target, depending on the ordered configuration (customer's application.) The instrument contains a high-resolution, Peltier cooled, Silicon PIN (Si-PIN) diode detector.

The TRACER III-V is a fully field portable analyzer with an integrated PDA (Personal Digital Assistant) computer (see Figure 1-1). The removable PDA provides the user interface for operating the instrument and contains the BrukerS1 analytical program. This program enables the user to select analytical modes, view spectra, and save data. The display is a 320×240 pixel color touch screen (TFT), which can be operated either with a fingertip or the stylus provided. Note: A PC is also supplied with the TRACER III-V when it is used for museum work. The instrument is factory calibrated for measurement of:

- Aluminum alloys
- Titanium alloys
- Low alloy steels
- Stainless steels
- Tool steels
- Nickel alloys
- Cobalt alloys
- Copper alloys

Figure 1-1 Portable configuration of the TRACER III-V

The TRACER III-V has a filter port where various filters may be inserted into the primary X-ray beam. Selection of a particular filter depends on the test Method chosen in the Bruker program (as described in section 5.6.4.) after the instrument power has been turned on.

In some cases, it may be more convenient to use the TRACER III-V in a stationary, bench top configuration. Figure 1-2 shows the TRACER III-V in the stand provided. There are grooves in the body and the handle which slide into the stand.

Figure 1-2 Bench top configuration

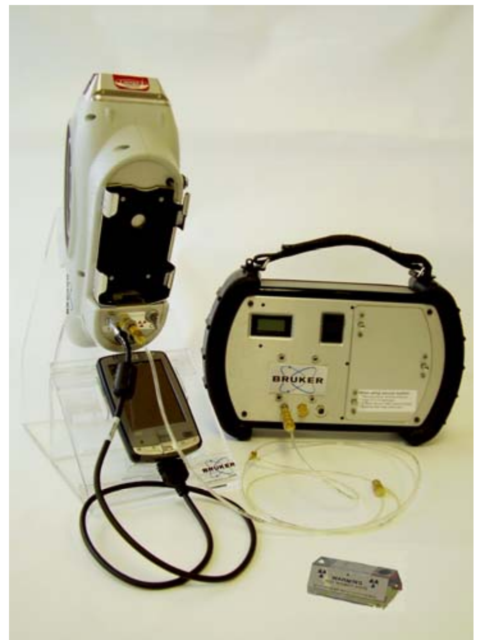


Figure 1-3 Vacuum configuration

When aluminum or titanium alloys are to be examined, the TRACER III-V should be used in vacuum mode. The vacuum pump attaches to the instrument with the provided tubing as shown in Figure 1-3. The clip-on window protector must be removed when in vacuum mode to obtain accurate readings.

Note: When the user selects an aluminum or titanium method in the BrukerS1 program, the software prompts the user to connect the vacuum pump. Additional information on selection of vacuum mode is contained in sections 4.2 and 5.6.

The slide vent valve vents the system when vacuum is not in use to prevent damage to the highly delicate Si-PIN detector. The TRACER III-V analyzer and the vacuum pump are battery operated. They may also be operated from A/C power. Note that for bench top operation, the instrument can be used with battery or A/C (line voltage) power.

2. TRACER III-V Operator Radiation Safety Requirements

2.1. What is Radiation?

- The term radiation is used with all forms of energy—light, X-rays, radar, microwaves, and more. For the purpose of this manual, radiation refers to invisible waves or particles of energy from X-ray tubes.

- **High levels of radiation may pose a danger to living tissue because it has the potential to damage and/or alter the chemical structure of cells. This could result in various levels of illness (i.e. mild to severe).**

- This section of the manual provides a basic understanding of radiation characteristics. This should help in preventing unnecessary radiation exposure to TRACER III-V users and persons nearby. The concepts have been simplified to give a basic picture of what radiation is and how it applies to operators of the TRACER III-V XRF Analyzer.

- Sections 2.2 – 2.4 characterize the TRACER III-V's safety features and controls and provide specific radiation profiles for the TRACER III-V analyzer.

- The user of a TRACER III-V XRF analyzer should study Appendix A to better understand the nature of radiation and how to be safe using handheld XRF analyzers. Appendix A will also provide perspective as to the exposure levels associated with the equipment.

2.2. X-ray Radiation from the TRACER III-V

X-rays are emitted at approximately a 53° angle from the aperture to the user's left (as viewed from the user's perspective), shown in Figure 2-1.

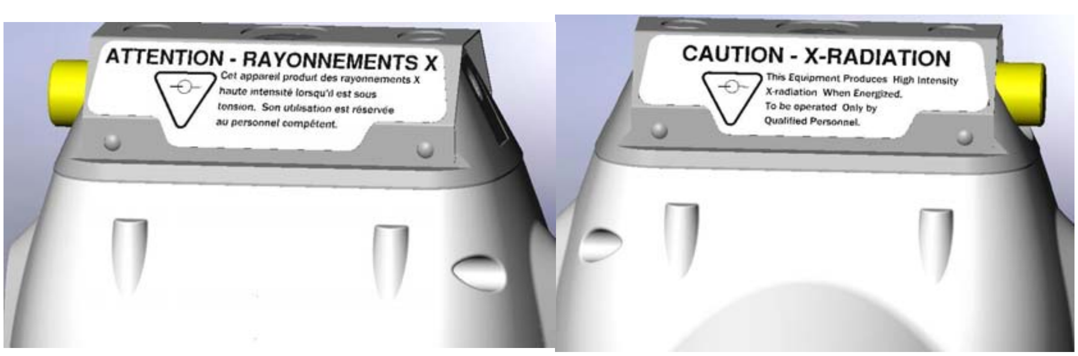


Figure 2-1 Emission of X-rays from the aperture

Radiation Scatter

Radiation scatter is produced whenever an absorbing material is directly irradiated from a nearby source. The atoms within the material become temporarily excited, producing X-rays before becoming stable again. This process, called X-ray fluorescence (XRF), is the principle of operation of the TRACER III-V XRF analyzer.

The X-ray tube within the TRACER III-V XRF analyzer is used to irradiate a chosen material at very close range with a narrow, collimated beam. The X-rays from the tube excite the atoms of the material, which then produce secondary X-rays that scatter in random directions. Hence, the term ***radiation scatter***.

Backscatter

The hand held XRF analyzer generates spectrum data by analyzing the specific secondary X-ray energies that travel from the sample under test to the instrument detector. Because X-rays travel in random directions, it is possible for an X-ray to miss the detector and be scattered in the direction of the operator. This is referred to as ***backscatter***.

Although the XRF analyzer is specifically designed to limit backscatter, there is always the possibility that a small number of X-rays may scatter beyond the detector. To ensure safe operation of the system, it is vital that the operator understands the radiation field. The radiation profiles provided in figures 2-8 and 2-9 illustrate the radiation field intensity for the TRACER III-V analyzer. The Radiation Profile section contains the detail on measurements of the radiation field. **The profiles should be studied carefully by anyone who operates the TRACER analyzer, in order to better understand and apply the practices of ALARA using time, distance and shielding.**

2.3. Hand Held XRF Analyzer Safety Design

The Bruker TRACER III-V series XRF Analyzers employ a miniature X-ray tube instead of a radioactive material to generate the X-rays. The general construction and the safety features described in this manual are the same for all TRACER III-V models.

Bruker AXS Handheld designed this hand held X-ray tube analyzer to conform to 21 CFR 1020.40 safety requirements for cabinet (i.e. closed beam) X-rays systems, with the exception of providing a totally enclosed beam.

Note: To prevent the operator from being directly exposed to the open X-ray beam, extensive safety circuit requirements including switches and failsafe lights have been incorporated.

The TRACER III-V series portable XRF analyzers were tested by TUV Rheinland against safety requirements of IEC 61010-1, “Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory user, Part I General Requirements.” The TRACER III-V portable XRF

analyzer passed the ionizing radiation leakage requirements in IEC 61010-1, section 12.2.1 of <1 µSv/hr (<0.1 mrem/hr) at 100mm. Since the instruments passed all of the safety requirements, the device was afforded the $_{C}TUV_{US}$ and GS Licenses, CB Global Scheme, and the general CE marks. The two licenses require periodic production audits by TUV Rheinland. See the TRACER III-V Safety Logic Circuit section for discussion on the warning lights, failsafe features, and labeling that has been incorporated to provide a high level of protection to the operator.

The TRACER III-V is a Hand Held (4 lb.) X-ray fluorescence (XRF) analyzer used as an analytical X-ray system. It employs a 4-watt, miniature (<15 mm diameter and <75 mm long) X-ray tube operated with an acceleration voltage range of 6 to 40 kV and a current range of 0.05-15 µA. In some cases, allowable ranges for X-ray tube voltage and current may be different to comply with local regulations. The tube target is dependent on the intended application and may contain material such as Rh, Ag, or Re.

The X-ray tube and high voltage (HV) power supply are sealed in a fluid filled assembly. The X-ray tube is shielded by a variety of materials to minimize any stray X-ray radiation. This is mounted in the XRF housing and the XRF housing is closed using tamper-proof fasteners.

The TRACER III-V X-ray beam is collimated through an aperture that is approximately 0.14 inches in diameter. The aperture is part of the beam collimator assembly. The radiation profiles illustrated in figures 2-8 and 2-9 illustrate the effectiveness of the design to limit X-ray emission to primarily that which passes through the aperture. See the Radiation Profile Section for discussion of the radiation profile measurements.

2.3.1 Safety Logic Circuit, Indicator Lights and Warning Labels

The TRACER III-V analyzer is designed with a Failsafe Safety System to prevent inadvertent operation of the analyzer. The safety system for the TRACER III-V analyzer consists of a key lock, two failsafe LED indicator lights, a trigger to activate X-rays, (a filter seal interlock) and an infrared proximity sensor to verify close proximity of a test sample. The function of each of the TRACER III-V's safety features is described below:

Primary Power Safety Key Switch - a keyed main power switch (Figure 2-3) is employed to control power to all components. The key switch must be turned on before any other actions can be initiated.

Software X-ray Radiation Warning – when starting the PDA software, a black and yellow X-ray Radiation Warning symbol and a text warning are displayed. The user must tap the PDA screen within the warning symbol with the stylus to proceed. No user input is accepted during the time the X-ray Radiation Warning is displayed.

Yellow Power On Indicator Light – when the key switch is turned on, the yellow light (Figure 2-3) will illuminate, indicating that the instrument is powered on. The light incorporates redundant LED elements for increased reliability.

If the instrument microprocessors detect a malfunction in the instrument, the yellow light flashes to alert the user. The redundant LED segments are incorporated in such a way that if either of the LED elements fails open, generation of X-rays is disabled.

Operator Trigger Interlock– when the trigger style switch is pulled, X-rays are generated if the rest of the safety circuit has been satisfied. The switch is spring-loaded and must be held in during measurements. If the switch is inadvertently released, the spring mechanism will return the switch to its idle position and stop X-ray generation.

Filter Seal Interlock – if the brass filter port cap is not in place, the operation of X-rays is prevented. The filter seal interlock consists of a safety interlock located in the collimator.

Infrared (IR) Proximity Sensor – the IR proximity sensor is used to confirm that the instrument has been placed against a sample. The sensor is located in the instrument nosepiece near the tube/detector opening. If the nosepiece is removed from the sample by a distance greater than 2.75 mm (~1/8 inch) the IR proximity sensor will stop X-ray generation. The exact distance is somewhat dependent on the sample material being tested.

Red X-ray On Indicator Light – when the trigger is pulled and the infrared sensor is engaged, the red light (Figure 2-3) will illuminate, indicating the generation of X-rays. The light incorporates redundant LED elements for increased reliability.

If one or both of the red light LEDs are burned out, X-rays will not be generated.

X-ray On Buzzer – the X-ray on buzzer will sound when the trigger is pulled to alert the operator that X-rays are being generated.

Low Count Rate Detection Safety Shutoff – while X-rays are being generated, the TRACER III-V microprocessor continually monitors raw count rate from the detector. If at any time during the measurement, the raw count rate falls below 500 counts per second, the microprocessor will stop X-ray generation since this indicates that no sample is in place. Should this occur, the operator must release the trigger and then re-start the test.

2.3.2 TRACER III-V XRF Safety Warning Labels

The TRACER III-V XRF analyzer has safety warning labels to alert the user and/or identify the functions of the controls. These labels are described below.

- To the right of the power (key lock) part of the analyzer (Figure 2-2) is a sign which says:

CAUTION:
X RADIATION

ATTENTION:
RAYONNEMENTS X

Figure 2-2 Caution radiation sign

- The control panel of the analyzer is labeled as illustrated in Figure 2-3

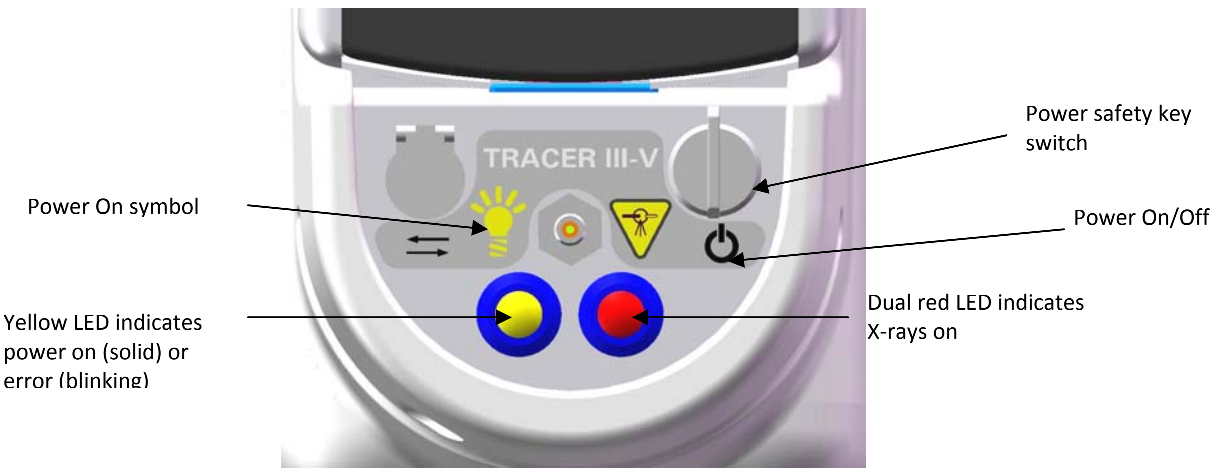


Figure 2-3 TRACER III-V control panel and indicator lights

- The yellow light, when illuminated, indicates that the high voltage (HV) power supply is energized. It has the following symbol above it.

- The red light, when illuminated, indicates that X-rays are being generated. It has the following label above it.

- The power (key lock) is labeled with an international Power On/Off symbol.

The vacuum window over the X-ray port carries a label with an X-ray warning (Figure 2-4)

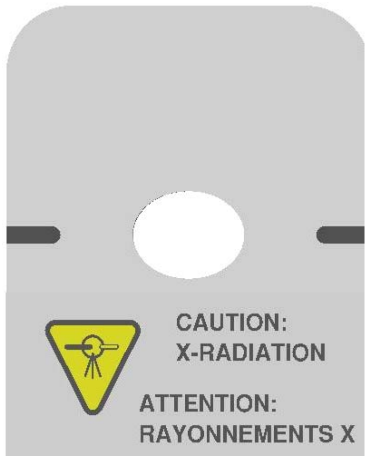


Figure 2-4 Vacuum window and X-ray warning label

An X-ray warning label is located near the nosepiece of the analyzer (Figure 2-5)

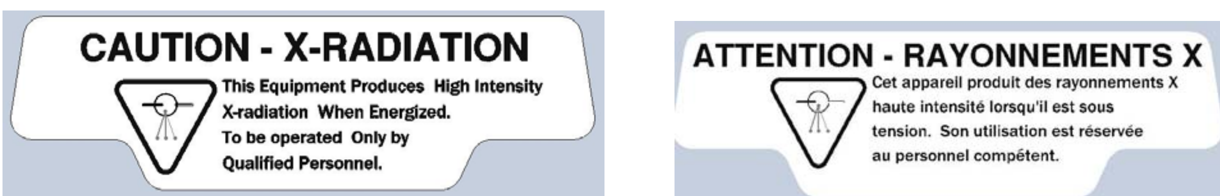


Figure 2-5 X-ray warning label near nosepiece of analyzer

On the Clip-On Window Protector that covers the analyzer’s nose (Figure 2-6) are two signs:

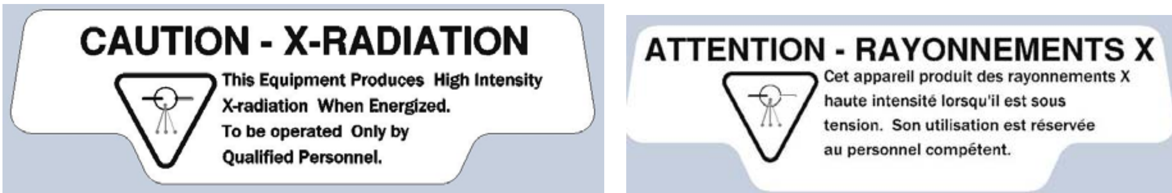


Figure 2-6 Clip-on window protector warning sign

A metal manufacturer’s plate (Figure 2-7) is mounted under the analyzer housing near the handle. In countries other than the USA, this label may be different based on local regulatory requirements.

Figure 2-7 Instrument base caution sigh

2.4. TRACER III-V Analyzer Radiation Profile

The radiation profile of the TRACER III-V analyzer shown in Figures 2-8 and 2-9 are for normal operating conditions. The readings in Figures 2-8 and 2-9 show the radiation background around the instrument in all directions. These values were obtained using a Bicron Low Energy Micro Rem ion chamber. These measurements indicate that the dose rate at 5 cm from any accessible surface was lower than 5.0 µSv/hr (less than 50 µrem/hr).

In Figure 2-8, measurements were made at 40kV and 10µA (the maximum current/voltage permitted) with the Ti/Al filter in place.

In Figure 2-9, measurements were made at 15 kV and 15µA without the Ti/Al filter.

A dosimetry expert performed a dosimetric study of the open beam profile for the TRACER III-V using thermoluminescent (TLD) dosimetric materials supplied by the Landauer Company. The

dosimetric materials were placed directly in the beam with no sample in place and all of the interlocks defeated. (NOTE: this is an artificial condition and should not be experienced during normal operation.) Measurements were made at several locations ranging from the surface to 100 cm. When looking at the instrument from the top, the X-ray beam exits the instrument at approximately 53 degrees to the left. These measurements were made at 40 kV and 10 µA, filter in and filter out. Measurements were also made at 40 kV @ 1.6 µA (filter in and out), 33 kV @ 0.9 µA (filter out) and 15 kV @ 11.8 µA (filter out). The results shown in Table 2-1 and Figure 2-10 illustrate the dose rate that could exist, **if the safety circuit did not exist.** These dose rates support the conclusion that an inadvertent exposure to the unenclosed direct beam would be extremely unlikely to produce a dose in excess of the regulatory limits.

NOTE: Open beam measurements are provided to illustrate the significant risk to the user associated with deliberate open beam operation. Operators following the appropriate operating instructions for the instrument should not receive any appreciable radiation dose from the instrument during normal use. The highest dose rates are close to the beam end of the device. Avoid placing hands or portions of the body in or near the beam path. NEVER ATTEMPT TO BYPASS OR DEFEAT THE SAFETY CIRCUIT.

The open beam dose rate meausrements were used to calculate the irradiation time necessary to receive the annual allowed dose for the most likely tissues at risk. These calculations are shown in Table 2-2.

NOTE: In the low X-ray region (3-60 keV), which is within the range of X-ray energies emitted by the TRACER III-V analyzer, the bone in the finger will absorb radiation about 3-5 times more than soft tissue. For this reason, DO NOT hold a test speciment in front of the beam window with the fingers in the direct beam or direct the beam at any part of the human body. (Reference: Health Physics 66(4);463-471;1994.)

Table 2-1 In-beam Skin Dose Rate (mrad/min) Measurements for Standard Instrument Settings with the Safety Circuit Defeated

Instrument Setting	Surface	5 cm	10 cm	30 cm	100 cm
40 KVp @ 10 µA, filter in	4832	552	109.8	31.7	8.7
40KVp @10 µA, filter out	9492	3211	1173	51.7	12.9
40 KVp @ 1.6 µA Filter in	159.6	59.2	Na[1]	6.1	1.5
40 KVp @ µA Filter out	715.8	Na[1]	136.2	10.3	2.25
33 KVp @ 0.9 µA Filter out	Na[1]	134	49.6	19.8	5.28
15KVp @ 11.8 µA Filter out	298	789	95.3	51.48	18.9

Note: 1. The vacant data cells (na) represent TLDs that were not shown in beam in the image film and therefore the results were not included

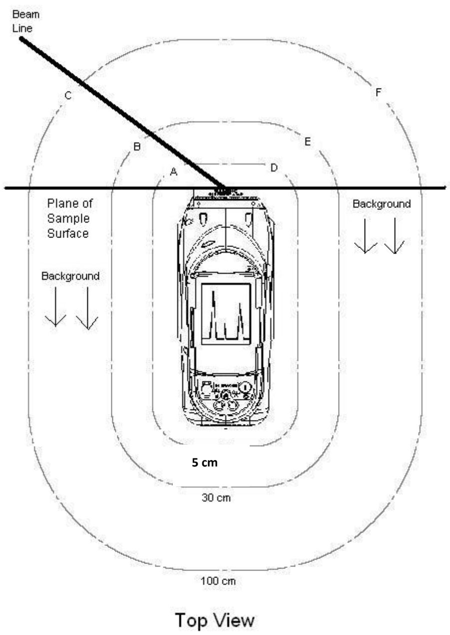
Table 2-2 Calculated Irradiation Time to Reach the Annual Limit with the Safety Circuit Defeated

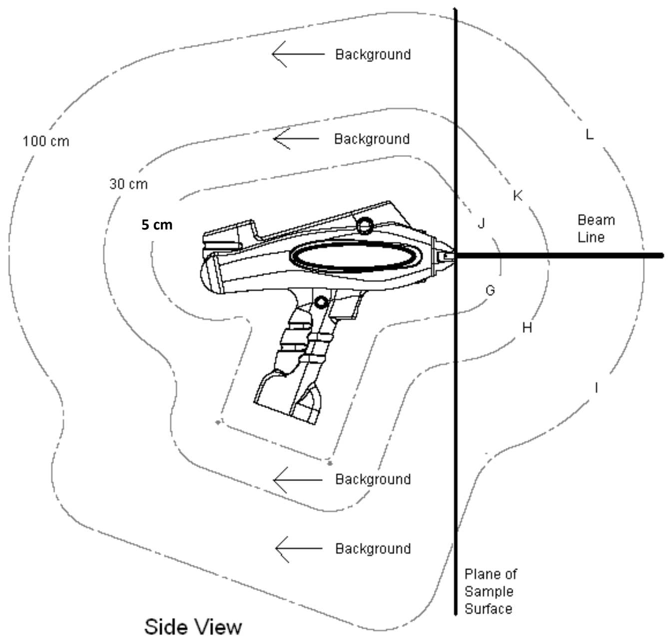
Location	Calculated Irradiation Time to Reach Permissible Limit for the Most Likely Tissues at Risk[1,2]							
	40 KVp@ 10 µA Filter in		40 KVp @ 1.6 µA Filter in		15 KVp @ 11.8 µA Filter out		40 KVp @ 10 µA Filter out	
Operating Parameters	Normal Use for Light Materials		Normal Use for Alloys		Normal Use for Al Allows		Worse Case Conditions	
	Eye	Skin	Eye	Skin	Eye	Skin	Eye	Skin
Emission surface[3]	3.1	10	94	310	50	170	1.6	5.3
5 cm	27	91	250	840	19	63	4.7	16
10	140	460	na[4]	na[4]	160	520	13	43

The first three columns under “Irradiation Time” are provided to show the time required to reach an annual limit for the three most commonly performed analyses if the safety circuit is defeated. **Note: These exposures can occur only if the safety circuit is defeated.** The fourth column was provided to show the Operating Parameters that could lead to the shortest irradiation time (i.e., Worse Case) that could occur **if the safety circuit is defeated**. These Irradiation Times should be considered approximate and as minimum values (i.e., irradiation times could be longer) because the dose rates values are overestimates.

Note: 1. Maximum permissible limit for the skin 500 mSv per year; Eye lens, 150 mSv per year
2. For the conditions of this survey, an absorbed dose of 1 mGy results in a Dose Equivalent of one mSv
3. Corrected values from Table 2-1 are used in calculations
4. na means data not available

Figure 2-8 Radiation Profile
(For 40 kV 10 µA, Duplex 2205 sample in beam)

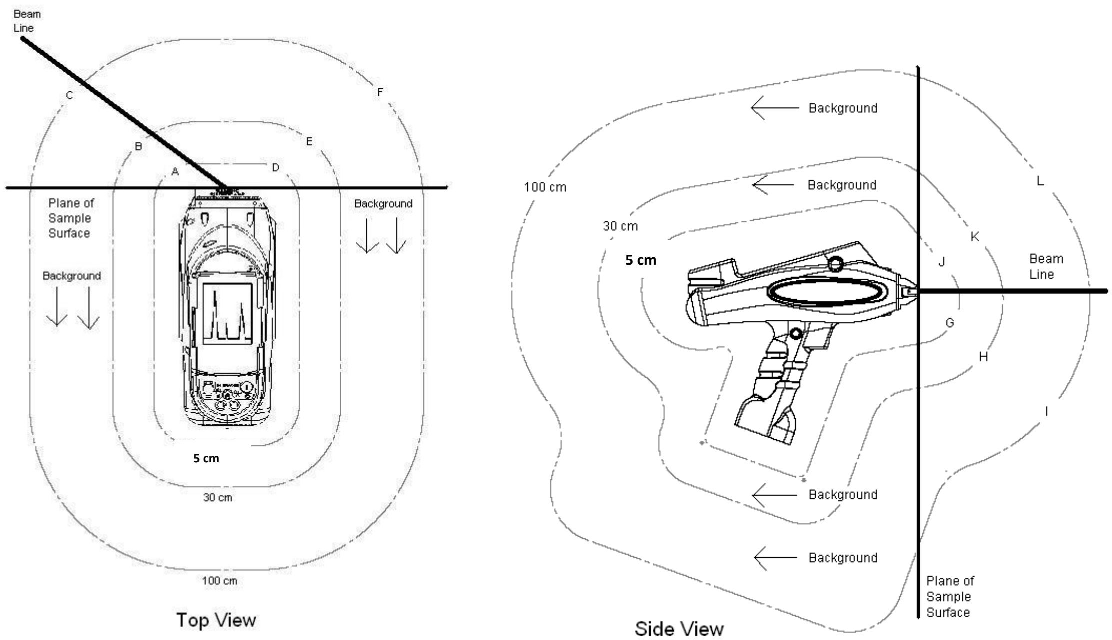




	Reading (µrem/hr)		Reading (µrem/hr)
A	5	G	13
B	bkgd	H	bkgd
C	bkgd	I	bkgd
D	5	J	15
E	bkgd	K	bkgd
F	bkgd	L	bkgd

Figure 2-8. Dose rates for the Bruker TRACER III-V XRF analyzer Normal Operation Configuration. Readings are in µrem/hr. All other locations on side, top, bottom and back of the analyzer are background (bkgd). Readings taken with a Bicron Model RSO-50 E low energy ion chamber survey instrument. Reference distances were measured from the effective center of the detector to the surface of the analyzer or sample. The indicated readings were the maximum noted for the distances and locations. Each reading was taken over a one minute period with the analyzer operating at approximately 10 µA and 40 kV, with a Ti/Al filter. **Note:** dose rates will vary based on current, energy, sample, target, collimator and windows.

Figure 2-9 Radiation Profile
(For 15 kV 15 µA, no filter, Al 2014 sample in beam)

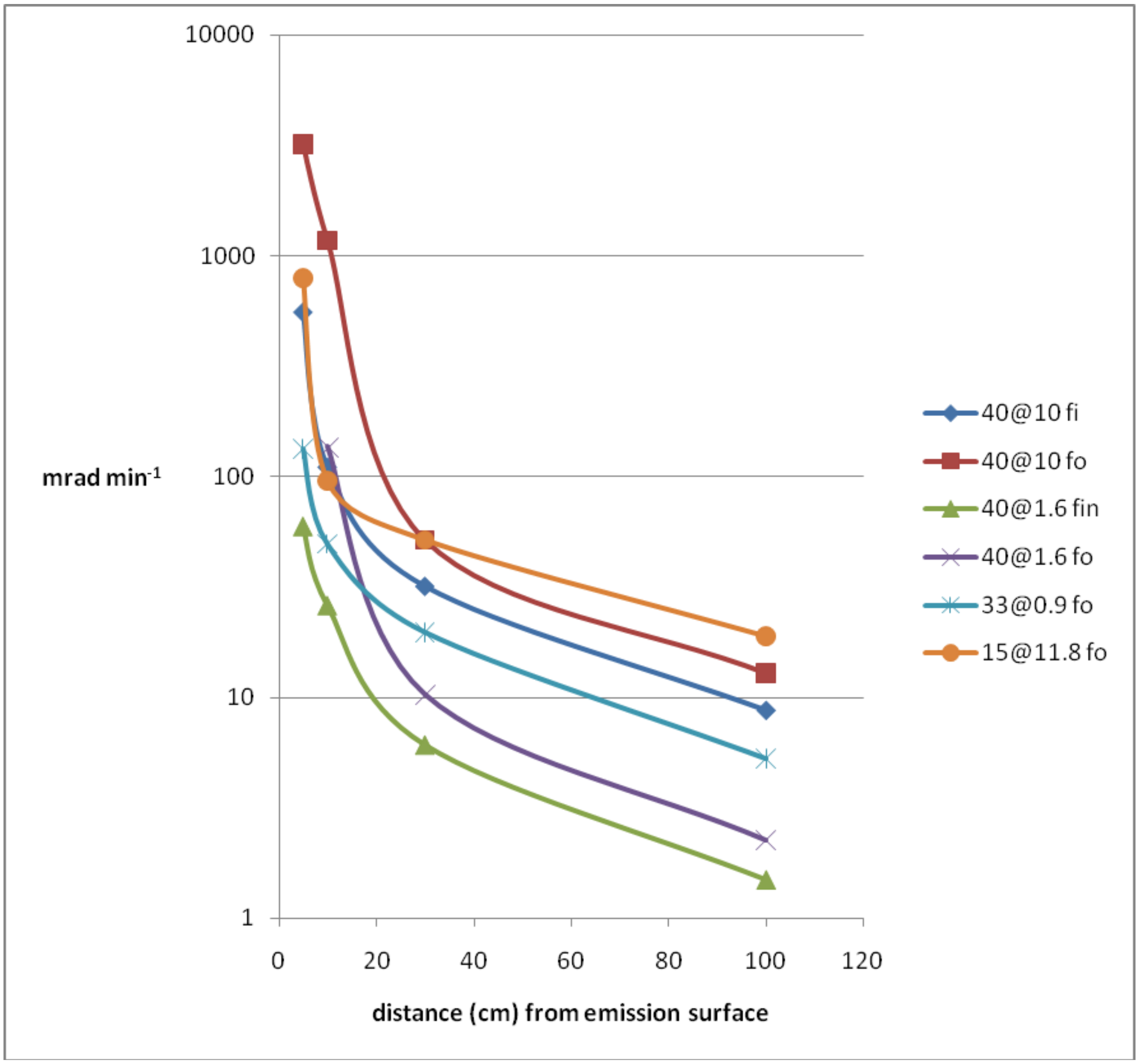


	Reading (µrem/hr)		Reading (µrem/hr)
A	8	G	2
B	bkgd	H	bkgd
C	bkgd	I	bkgd
D	3	J	2
E	bkgd	K	bkgd
F	bkgd	L	bkgd

Figure 2-9. Dose rates for the Bruker TRACER III-V XRF analyzer Normal Operation Configuration. Readings are in µrem /hr. All other locations on side, top, bottom and back of the analyzer are background (bkgd). Readings taken with a Bicron Model RSO-50 E low energy ion chamber survey instrument with the beta shield open. Reference distances were measured from the effective center of the detector to the surface of the analyzer or sample. The indicated readings were the maximum noted for the distances and locations. Each reading was taken over a one minute period with the analyzer operating at approximately 15 µA and 15 kV, without a filter. **Note:** dose rates will vary based on current, energy, sample, target, collimator and windows.

11

Figure 2-10 The average skin dose rate in the open beam. mrad/min = 100 mGy/hr.



2.5. Using the TRACER III-V Safely

When the TRACER III-V is used properly, X-ray radiation from instrument poses no potential for harm to the user, nearby persons, or objects.

A properly trained user will use the TRACER III-V in a manner that eliminates or minimizes the risk of unnecessary exposure to X-ray radiation.

Safe use of any XRF device is based on the principles of:

- Time – managing the amount of time during which X-rays are being produced by the instrument

- Distance – keeping all parts of the user's body as far away from the X-ray producing nosepiece as possible, keeping the X-ray producing nosepiece pointed in a direction away from nearby persons, and keeping nearby persons away from the instrument during use.

- Shielding – ensuring that the TRACER III-V analyzer is mechanically intact and sound, and using the shielded sample cup accessory when measuring physically small or unknown samples which might permit unnecessary X-ray radiation to escape.

Collectively, these practices are known by the phrase "**As Low As Reasonably Achievable**", or the acronym **ALARA**. User practice to implement ALARA will be further discussed in Appendix A, "Basic Radiation Safety Information", and during TRACER III-V user training

2.6. Radiation Safety Tips for Using the XRF Analyzer

All TRACER III-V analyzer operators should follow the minimum safety requirements discussed below. When handled properly, the amount of radiation exposure received from the TRACER III-V XRF analyzer will be negligible. The following safety procedures are provided to help ensure safe and responsible use:

- **Do not allow anyone** other than trained and certified personnel to operate the TRACER III-V XRF Analyzer.
- Be aware of the direction that the X-rays travel when the red light is on and do not place any part of your body (especially the eyes or hands) near the X-ray port during operation (see the Radiation Profile Section for measurement information).

WARNING: *No one but the operator(s) should be allowed to be closer than 1 meter (3 feet) from the* TRACER III-V*, particularly the beam port. Ignoring this warning could result in unnecessary exposure.*

Figure 2-11 Safe use of the TRACER III-V

Figure 2-12 Unsafe use of the TRACER III-V

WARNING: *Never hold a sample to the X-ray port for analysis by hand. Hold the instrument against the sample.*

Figure 2-13 Safe use of the TRACER III-V

Figure 2-14 Unsafe use of the TRACER III-V

- The infrared (IR) sensor located on the nosepiece is designed to prevent the emission of X-rays from the X-ray port without a solid object being in direct contact with the nosepiece.

WARNING: *The operator should never defeat the IR sensor in order to bypass this part of the safety circuit. Defeating this safety feature could result in unnecessary exposure of the operator. When using the bench top configuration, obtain a sample large enough to cover both the analyzer window and the IR sensor. If a sample is not sufficiently large to cover both the analyzer window and the IR sensor, then the optional safety shield accessory should be used for testing that sample.*

Figure 2-15 Safe use of the TRACER III-V in the test stand

Figure 2-16 Unsafe use of the TRACER III-V in the test stand

- Pregnant women who use the TRACER III-V Analyzer should be aware that improper handling or improper use of the instrument could result in radiation exposure which may be harmful to a developing fetus.
- Wear an appropriate dosimeter if required by a regulatory agency when operating the TRACER III-V.
- The operator is responsible for the security of the analyzer. When in use, the device should be in the operator's possession at all times (i.e. either in direct sight or a secure area). The key should not be left in an unattended analyzer. Always store the instrument in a secure location when not in use; also store the key in a location separate from the analyzer to avoid unauthorized use.
- During transport to and from the field, store the instrument in a cool, dry location (i.e. in the trunk of a car rather than in the back seat.).

Figure 2-17 Safe use of the TRACER III-V

Figure 2-18 Unsafe use of the TRACER III-V

2.7. Correct TRACER III-V Positioning

Always place the analyzer on the sample, or when testing small parts, place the TRACER III-V in the stand and place the sample onto the nose of the analyzer.

When testing very small samples, use the clip-on sample holder and radiation safety shield, and keep a safe distance from the nosepiece of the analyzer while X-rays are being generated.

Thin or Light Element Samples

A less obvious risk of excess radiation exposure occurs when testing thin samples. Part of the radiation coming from the X-ray tube is of a sufficiently high energy to penetrate thin samples, especially if the sample is composed of "lighter" (low atomic number) elements. The following tables illustrate relative intensities after the radiation has passed through aluminum/iron sheets of various thicknesses (the tube is operated at 40kV and is filtered by a 1.27 mm thick aluminum sheet inside the instrument). When testing thin samples, use of the radiation safety shield is recommended.

Table 2-2: Intensity of X-ray Radiation after Sample Penetration

Aluminum Sheet Relative Intensities

Thickness	*Relative Intensity*
0 mm	*100%*
1 mm	*46%*
2 mm	*26%*
3 mm	*16%*
4 mm	*11%*
5 mm	*7.5%*
10 mm	*1.5%*

Iron Sheet Relative Intensities

Thickness	*Relative Intensity*
0.0 mm	*100%*
0.1 mm	*23%*
0.2 mm	*9%*
0.3 mm	*4%*
0.4 mm	*2.1%*
0.5 mm	*1.1%*
1.0 mm	*0.08%*

An aluminum sample must be quite thick before it absorbs a substantial amount of the radiation, while iron provides much better absorption. The transmission difference is very important and demonstrates why it is not a safe practice to measure samples while holding them in your hand.

2.8. In Case of Emergency

If a person without proper training attempts to operate the TRACER III-V analyzer, resulting X-ray emission from the X-ray tube could be harmful to the operator or others nearby. If a TRACER III-V analyzer is lost or stolen, notify the local law enforcement and regulatory authority as soon as possible.

In the event of an accident with, or damage to the TRACER III-V analyzer, immediately turn off the device, and remove the battery pack. Then follow the steps below.

Minor Damage

If any hardware item appears to be damaged, even if the analyzer remains operable, immediately contact Bruker AXS Handheld at (800) 466-5323 or (509) 783-9850 for assistance. Use of a damaged analyzer may lead to unnecessary radiation exposure and/or inaccurate measurements.

Major Damage

If the analyzer is severely damaged, immediately stop use of the instrument and contact Bruker AXS Handheld immediately and notify the appropriate regulatory agency in your state or country. Care must be taken to ensure that personnel near the device are not exposed to unshielded X-rays that may be generated (i.e. if the safety logic circuit has been damaged and is not functional). Immediate removal of the battery pack will stop all X-ray production.

Loss or Theft

Should a TRACER III-V analyzer be lost or stolen, immediately notify the appropriate regulatory agency in the state or country in which the device was located. Additionally, immediately notify local law enforcement authorities and Bruker AXS Handheld.

Take the following precautions to minimize the chance of loss or theft:

- Never leave the analyzer unattended when in use.
- When not in use, always keep the device in its shipping container and store it in a locked vehicle or in a secure area.
- When not in use, keep the key separate from the analyzer.
- Maintain records to keep track of all instruments owned and the operators assigned to use them and where they were used.
- Never share your password with another user.

2.9. License/Registration Requirements

Bruker TRACER III-V X-ray Tube XRF Analyzer

The owner/operator of Bruker TRACER III-V X-ray Tube XRF analyzer, Canadian Version is subject to license and/or registration under Canadian Federal Regulations. The owner/operator should:

- Comply with Canadian Federal Regulations (see Section iii above).
- Never remove labels from the analyzer.
- Comply with all instructions and labels provided with the device.
- Store the analyzer in a safe place where it is unlikely to be stolen or removed accidentally.
- Keep the key separate from the analyzer.
- Maintain records of the storage, removal, and transport of the analyzer. Know its whereabouts at all times.
- Monitor operator's compliance with safe use practices. Use dosimetry where required.
- Report to the local regulatory agency any damage to the shielding and any loss or theft of the analyzer.
- Only sell or transfer the analyzer to persons registered to receive it.
- Notify your regulatory agency upon the transfer or disposal of the X-ray unit.

2.10. Transportation Requirements

Bruker TRACER III-V X-ray Tube XRF Analyzer

An owner/operator of a TRACER III-V X-ray tube XRF analyzer, Canadian Version may only transfer custody of the analyzer to authorized (licensed/registered) individuals. However, the user must notify the destination State's or Province's regulatory Agency usually at least one week in advance of intent to transport and use the instrument in that State. When transferring control or ownership of the TRACER III-V, the owner must verify that the recipient is authorized to receive the analyzer. No verification is required when returning it to Bruker AXS Handheld, the original manufacturer.

Check with your local regulatory agency prior to transporting or shipping a TRACER III-V XRF Analyzer. For travel or shipment within the U.S., there are no special Department of Transportation (DOT) interstate travel and shipping regulations for the TRACER III-V. The analyzer may be shipped using any available means. If the user is flying, it is recommended that

the device should be checked through due to possible concerns about the X-ray unit in the main cabin.

The owner is responsible for ensuring that all requirements of the local jurisdiction where the X-ray Tube XRF is to be used are followed. To prevent inadvertent exposure of a member of the public in case the X-ray Tube XRF Analyzer is lost or stolen, the key should be maintained and shipped separately. Principal Components of the TRACER III-V

3. Principal Components of the TRACER III-V

3.1. Principal TRACER III-V Components

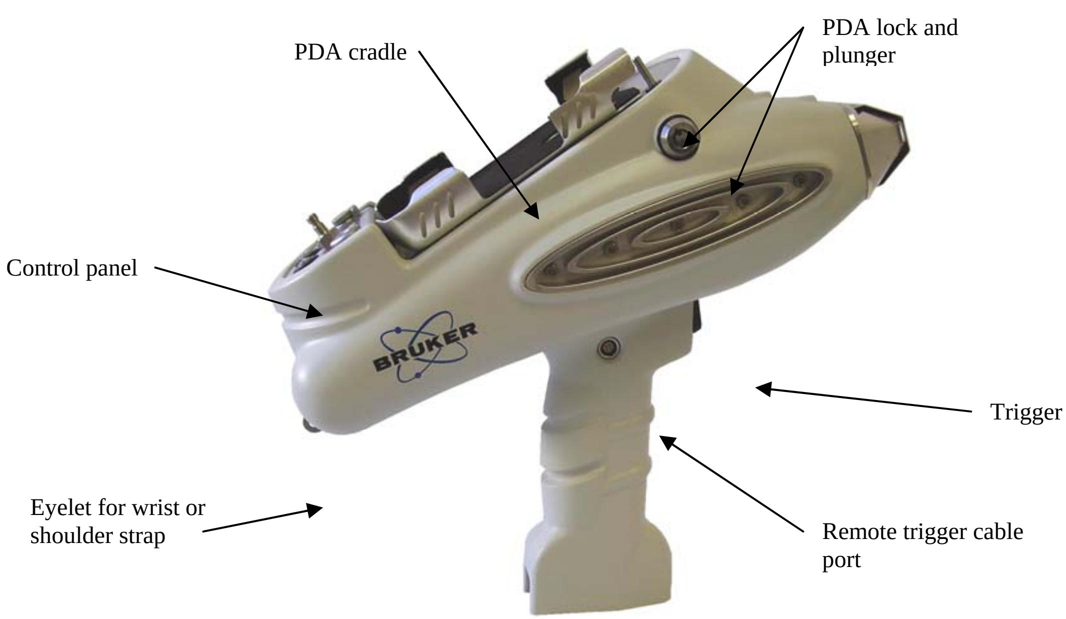


Figure 3-1 TRACER III-V right side profile

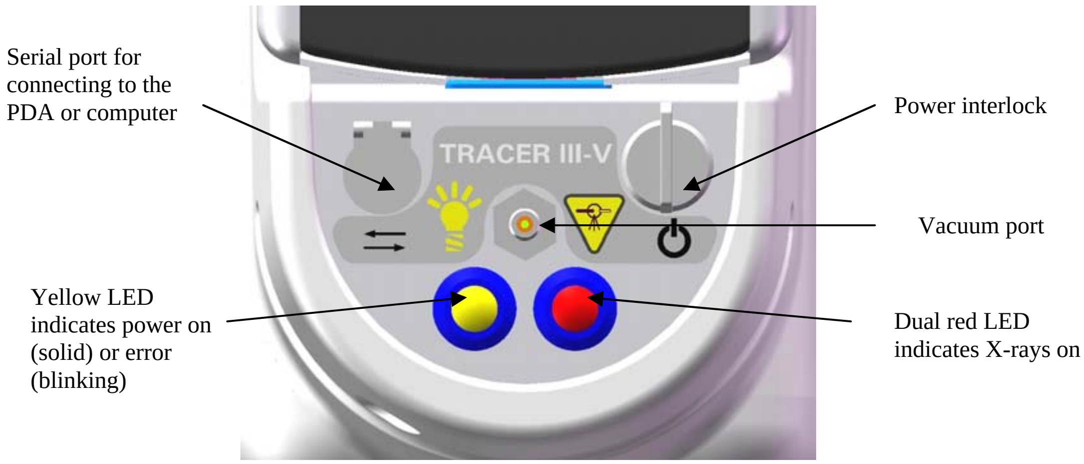


Figure 3-2 TRACER III-V control panel

3.2. Principal PDA Components

Figure 3-3 iPAQ PDA

3.3. Principal Vacuum Pump Components

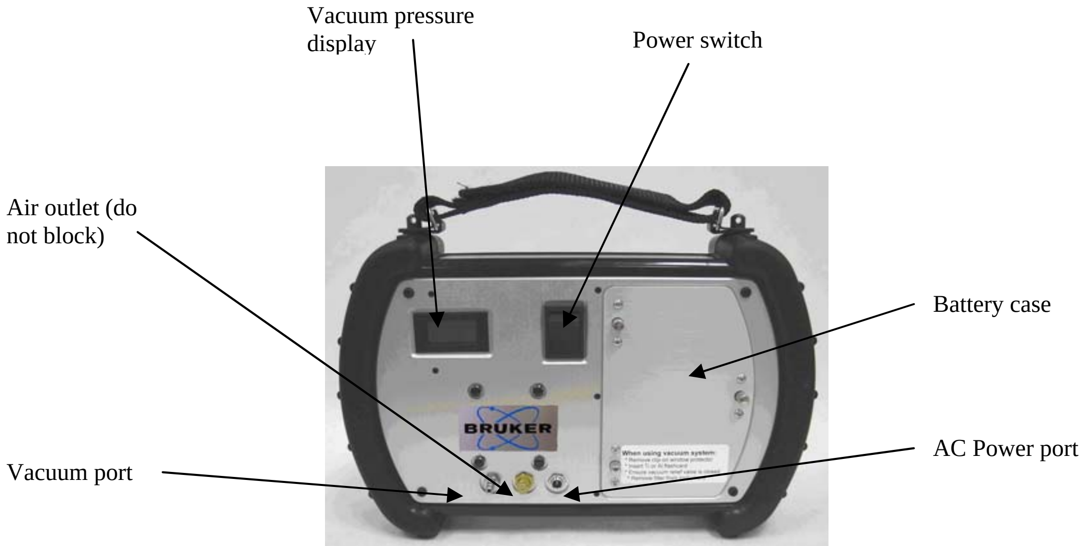
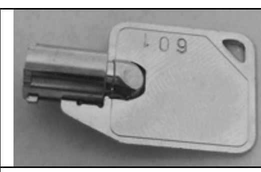
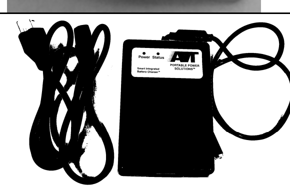
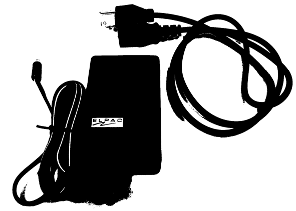
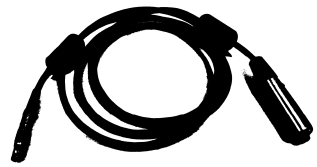
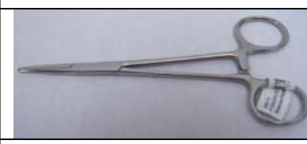
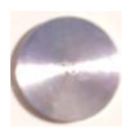


Figure 3.4: Vacuum Pump

3.4. Included Accessories

These accessories are included with the TRACER III-V. For replacement parts, call Bruker AXS Handheld Inc at (509) 783-9850.

TRACER III-V Accessories			
Power Interlock Keys (2)		PDA Release Keys (2)	
Li-IonBattery Packs (2)		Battery Charger (AVT) and Power Cord	

TRACER III-V Accessories			
Instrument Stand with PDA cradle		A/C Power Supply (Elpac) and Power Cord	
Clip-on Window Protector		Remote Trigger Cable	
Replacement Vacuum Windows (10)		Filter Kit	
Shoulder Strap		Wrist Strap	
Ti/Al Filter		Forceps	
Duplex 2205 Sample		Aluminum 2024 Sample	
Clip-on Sample Holder		Shipping Case	

PDA Accessories			
Non-Vacuum Flash Card		A/C Power Supply	
Null Modem Cable		Sync Cradle/Battery Charger	
Display Covers		Stylus	

Laptop Accessories			
PC Download Cable		USB to Serial Cable	

Vacuum Pump Accessories			
Li-Ion Battery Packs (2)		Universal Smart Battery Charger	

Vacuum Pump Accessories			
Vacuum Tubing (may be clear or black)		A/C Power Supply (Elpac) and Power Cord	
Shoulder Strap		Shipping Case	

3.5. Additional Available Accessories

These accessories are available to be used with the TRACER III-V. To order these parts, call KeyMaster at (509) 783-9850.

Wire Adaptor	The wire adaptor attaches to the clip-on window protector and narrows the aperture to a thin slit that allows smaller diameter pieces to be examined.
Safety Shield	The safety shield is used in bench top operations to protect the user from accidental exposure to x-rays. For the case of small test samples, it can safely cover the IR sensor while the sample covers the aperture.
Replacement Windows	Additional replacement vacuum or kapton windows are also available.

3.6. Operating Conditions of the TRACER III-V

Temperature	Instrument -10 °C to +50 °C Charger +5 °C to +45 °C
Humidity	Continuous operation at 20% to 95% RH, no condensation. Instrument should not be exposed to rain. The charger is designed for indoor use only.
Shock Resistance	During transportation and operation, the instrument must not be dropped or left in extreme conditions that might damage its sensitive components. To achieve optimum accuracy, avoid movement or vibration during measurements.

Charging Line Voltage	Instrument 90 – 240 V, 50 – 60 Hz. iPAQ PDA 100 – 240 V, 50 – 60 Hz Charger 100 – 260 V, 45 – 70 Hz

4. Preparing the TRACER III-V for Use

4.1. Determine Power Configuration

All of the components can be used with either A/C power or battery power.
The batteries for the TRACER III-V and the vacuum pump should arrive fully charged. However, it is necessary to fully charge the PDA batteries prior to using the instrument for the first time. In addition, if the PDA has not been used for a week or more, it is wise to recharge it prior to use.

4.1.1 TRACER III-V

4.1.1.1. A/C Power

To operate the TRACER III-V on A/C power, ensure that the instrument is off and remove the batteries (see Figure 4.2 below). Plug the A/C power supply into the handle of the TRACER III-V, connect the power cord to the A/C power supply, and then plug the power cord into a standard wall outlet.

Figure 4-1 Hooking up A/C power for TRACER III-V

4.1.1.2. Battery Power/Charging the Batteries

The TRACER III-V uses Li-ion batteries that are contained in the handle of the instrument. Ensure that the instrument is off prior to removing the batteries. To change the battery, push the button on the bottom of the handle, and then pull on the black base to remove.

Figure 4-2 Removing the battery from the TRACER III-V

To charge the battery, connect the battery to the AVT battery charger. Connect the battery charger and the power cord and then plug the power cord into a standard wall outlet. The orange light on the charger indicates that the battery is charging and the green light indicates that the charge is complete.

Figure 4-3 Charging the TRACER III-V batteries

To reinstall the battery, simply insert the battery in the handle of the instrument until a click is heard. The batteries take approximately 4 hours to charge. A brand new, fully charged battery will operate the TRACER III-V for approximately 4 hours.

4.1.2 PDA

4.1.2.1. A/C Power

To operate the PDA on A/C power, plug the A/C power supply into the PDA and then plug the cord into a standard wall outlet.

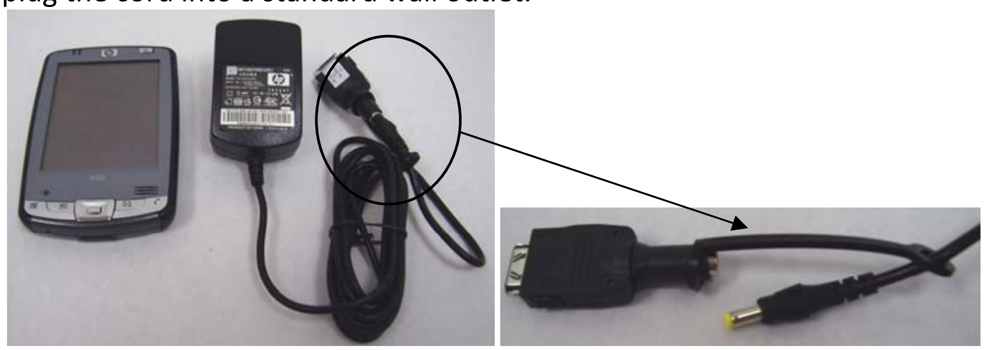


Figure 4-4 Hooking up A/C power to the PDA

4.1.2.2. Battery Power/Charging the Batteries

If the PDA is still on the TRACER III-V, ensure that the PDA and TRACER are powered off. Remove the PDA by unlocking the PDA key lock to move the plunger downward and sliding the PDA forward in the cradle.

Figure 4-5 Insert PDA release key into lock and turn key to move plunger

Either connect the PDA to the A/C adaptor and then plug it into a standard wall outlet or place the PDA in the cradle, connect the A/C adaptor to the cradle, and then plug it into a standard wall outlet. An orange LED on the top left of the PDA face will flash to indicate that the PDA battery is charging. When the orange LED is on continuously, the PDA battery is fully charged.

Figure 4-6 Charging the PDA with the wall charger

Figure 4-7 Charging the PDA with the cradle

For more information on the PDA, please refer to its operations manual.

4.1.3 Vacuum Pump

4.1.3.1. A/C Power

To operate the vacuum pump on A/C power, plug the A/C power supply into the port on the front of the vacuum pump, connect the power cord to the A/C power supply, and then plug the power cord into a standard wall outlet.

Figure 4-8 Hooking up A/C power to the vacuum pump

4.1.3.2. Battery Power/Charging the Batteries

The vacuum pump uses nickel metal hydride (NiMH) batteries. Ensure that the instrument is off prior to removing the batteries. To change the battery, turn the three knobs approximately one-quarter turn counterclockwise to remove the battery cover. Unclip the white connector and pull the battery out of the compartment.

Figure 4-9 Removing the battery from the vacuum pump

To charge the battery, connect the battery to the universal smart battery charger. Ensure that the switch is set to 1.8A. Connect the battery charger and the power cord and then plug the power cord into a standard wall outlet. The orange light on the charger indicates that the battery is charging and the green light indicates that the charge is complete.

`Figure 4-10 Charging the vacuum pump battery

To reinstall the battery, reattach the white connector and place the battery back into the compartment on the vacuum pump. Replace the battery cover and turn the three knobs approximately one-quarter turn clockwise to lock it in place. The batteries take approximately 4 hours to charge. A brand new, fully charged battery will operate the vacuum pump for approximately 5 hours.

4.1.4 Important Information about Li-ion Batteries

Li-ion batteries do not have a memory and work best under low strain conditions. To prolong the life of the batteries:

- Recharge the Li-ion batteries frequently.
- Fully discharge the batteries (by using them in the instrument) after every 30 charge cycles.
- During charging, the ambient temperature should be between +5 °C and +45 °C.
- For prolonged storage, keep the battery charged to about 30% to 50% and store at room temperature. If the battery is not used for extended periods of time, recharge about once per year to prevent over discharge.

GENERAL BATTERY WARNINGS

- Misusing the battery can cause the battery to get hot, ignite, or rupture and cause serious injury.
- Do not place the battery in a fire or heat the battery. Do not place the battery in direct sunlight or use or store batteries in the car in hot weather. Do not place battery in the microwave oven, high pressure container, or induction cookware.
- Do not pierce the battery with nails or other sharp objects, strike the battery with a hammer, step on the battery, or otherwise subject it to strong impacts or shocks.
- Do not expose the battery to water or saltwater or allow the battery to get wet.
- Do not disassemble the battery as this may disconnect its safety protection devices.
- Charge the battery only with the charger that is intended to charge the battery.
- Do not use any other devices to discharge the battery. The battery should be discharged by using the instrument only.

4.2. Determine Configuration

Take a look at what will be analyzed. Items that contain light elements, such as aluminum or titanium alloys, must be analyzed in vacuum mode with the filter and clip-on window protector removed and the correct flash card inserted into the PDA. The flash card establishes different voltage and current settings for the instrument, which is critical for determining accurate measurements for aluminum, titanium, or other light element materials.

4.2.1 Changing the Filter

To examine iron, steel, nickel, cobalt or copper (bronze) alloys, insert the Ti/Al filter with the aluminium side (lighter side) facing toward the aperture and the titanium side (darker side) facing the instrument. To examine aluminum, titanium, or other light elements, remove all filters.

Figure 4-11 The Ti/Al filter - Aluminum is the light colored side, Titanium is the dark colored side

To insert or remove the Ti/Al filter, unscrew the brass knurled screw. Use the forceps to insert or remove the Ti/Aluminum filter. When using the filter, be sure that the aluminium (lighter) side is facing away from the instrument and the titanium (darker) side is facing toward the instrument.

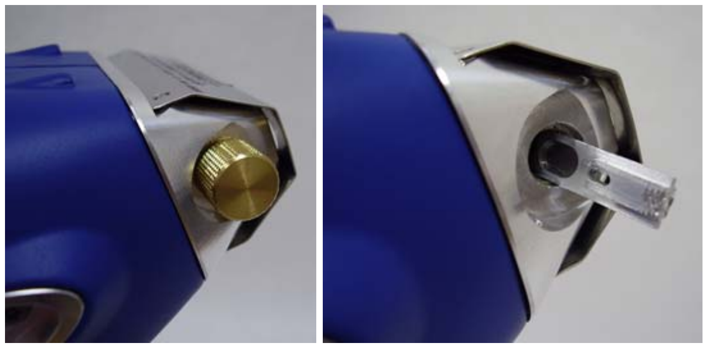


Figure 4-12 Inserting or removing the Ti/Al filter

Be sure to reinstall the brass knurled screw before using the instrument. Do not operate the TRACER III-V without the brass knurled screw in place.

IMPORTANT: The brass knurled screw should be tightened only finger tight.

4.2.2 Changing the Vacuum Window

Ten replacement vacuum windows are included with the TRACER III-V. The vacuum window protects the delicate instrumentation from dust and debris in normal operation and also provides a vacuum seal during light element analysis. The vacuum window only needs to be replaced when it has been damaged and can no longer hold a vacuum.
When changing a damaged window, be sure that the TRACER III-V is powered OFF. Carefully peel the tape from the nose of the instrument. Now that the nose is exposed, be careful not to allow dust and debris into the aperture which may damage sensitive instrumentation. Peel the backing off of one replacement window and line up the aperture with the window. Press the tape such that there are no air bubbles, gaps, or creases to allow air to enter the nose. Carefully use a fingernail to press firmly around the aperture for a good seal.

4.2.3 Clip-on Window Protector and Sample Holder

When analyzing light elements (such as materials containing aluminum or titanium) in vacuum mode, be sure to remove the clip-on window protector. To remove the clip-on window protector, grip it firmly on both sides and lift off of the instrument. To reinstall, gently press the clip-on window protector over the

nose of the instrument, lining up the four notches on the outside of the window protector with the bumps that hold it in place.

Figure 4-13 Installing /removing the clip-on window protector

To analyze small samples or to have a flat surface on which to work, install the clip-on sample holder instead of the clip-on window protector.

Figure 4-14 Clip-on sample holder installed on the TRACER III-V

Use care so that an object does not puncture the window on the instrument (see section 4.2.2 for instructions on how to replace the windows). Do not use the instrument if the window has been punctured.

4.2.4 Connecting the Vacuum Pump

To analyze light elements such as aluminum and titanium, attach the vacuum pump to the TRACER III-V. Be sure to remove the filter (see section 4.2.1) and remove the clip-on window protector (see section 4.2.3). Connect the vacuum tubing between the vacuum pump and the TRACER III-V, ensuring that the hose with the vacuum release valve is connected to the pump. Close the vacuum release valve. Turn the vacuum pump on. The vacuum system is ready when the display reads 5 torr or less.

Figure 4-15 Attaching the vacuum tubing

Vacuum release valve in
open position

Vacuum release valve in
closed position

To vacuum pump

To TRACER

Figure 4-16 Opening/closing the vacuum release valve

IMPORTANT: UPON JOB COMPLETION AND BEFORE REMOVING THE PUMP FROM THE INSTRUMENT, OPEN THE VACUUM RELEASE VALVE. Failure to open the vacuum release valve prior to removing the vacuum tubing from the vacuum pump or the instrument will damage the highly sensitive Si-PIN detector.

4.2.5 Inserting the Flash Card

Select the flash card that most closely matches what is being analyzed. There are flash cards for non-vacuum mode, titanium alloys, and aluminum alloys. It is important to select the appropriate card for analysis because the information on the card sets the appropriate voltage and current settings for the instrument. Using incorrect voltage and current settings can cause inaccurate results. Do not use flash cards from other instruments as they will have different calibration settings.

To change the flash card, ensure that the PDA is powered off. Gently pull out the card in the slot and carefully insert the next flash card into the slot. Do not force the flash card into the PDA. If it does not insert fully, it may be inserted up-side-down. Remove the flash card and try it in the other direction.

Figure 4-17 Installing/removing the flash card from the PDA

Do not change the flash card while the PDA is installed in the instrument. If necessary, power off the instrument and remove the PDA (see Figure 4-5).

4.2.6 Sampling Configuration

The TRACER III-V can be used as a hand-held device, as a bench top instrument, or in a tripod, depending on the analyst’s needs.

4.2.6.1. Hand Held Configuration

To use the TRACER III-V as a hand held device, be sure to secure the wrist strap or shoulder strap. To attach the wrist strap, wind the ring through the eyelet at the back of the instrument (see Figure 1-1).
To attach the shoulder strap, twist the knob counter clockwise until it has moved away from the bar as far as it will go. Push down on the knob all the way and turn the knob to remove the foot from the bar. Feed the bar through the eyelet at the back of the instrument. Push down on the knob all the way and turn the knob until the foot will lock into place when the knob is released. Turn the knob clockwise until it is all the way back toward the bar again.

4.2.6.2. Bench Top Configuration

To set up the instrument stand, lift the long side (screw may need to be loosened to lift the side fully) and tighten the screw to hold it in place. Lift the shorter side such that the legs swing down and fit into the grooves in the base of the instrument stand. Attach the PDA cradle with the velcro dots.

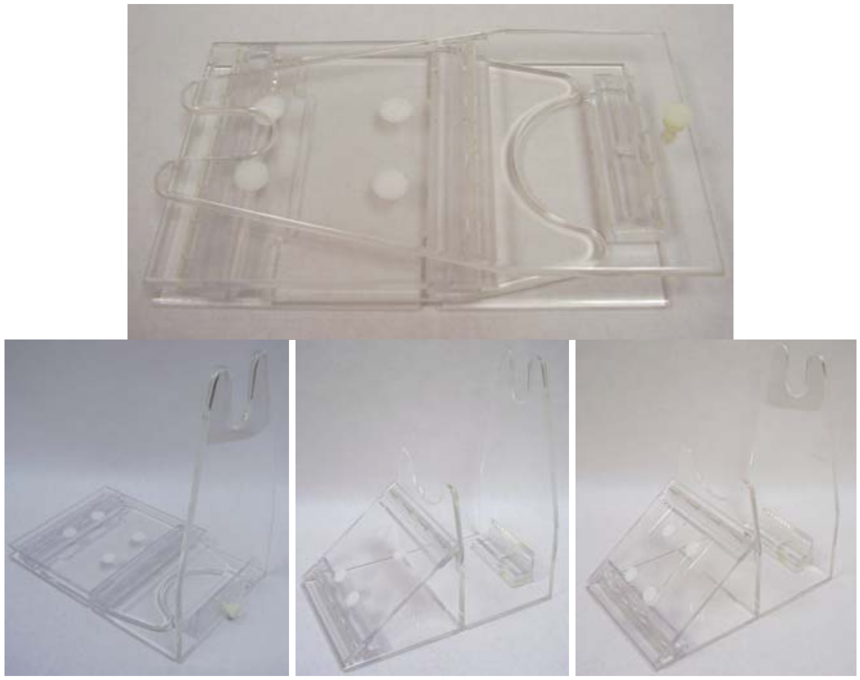


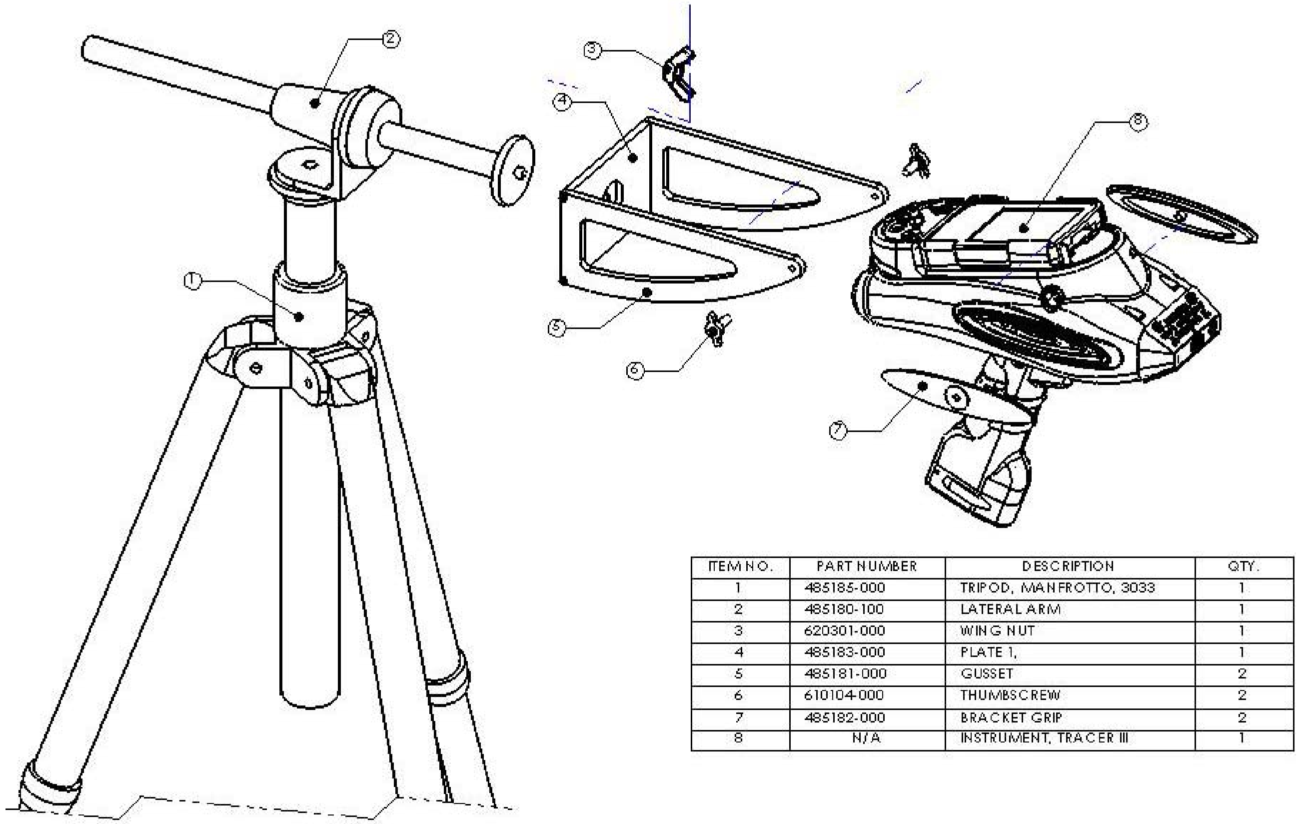
Figure 4-18 Setting up the instrument stand

To use the TRACER III-V in the bench top configuration, remove the PDA from the instrument's PDA cradle (see Figure 4-5). Place the instrument into the stand by aligning the grooves in the body and handle and sliding it onto the stand (see figure 1-2). Connect the PDA to the TRACER III-V with the null modem cable and place the PDA snugly into the PDA cradle on the instrument stand.

4.2.6.3. Tripod Configuration

To assemble the tripod configuration (see figure 3-19):

- Attach the lateral arm (2) to the tripod.
- As necessary, assemble the bracket by attaching the gussets (5) to the plate (4).
- Attach the instrument (8) with the bracket grips (7) to the bracket using the thumb screws (6).
- Attach the bracket and instrument assembly to the lateral arm (2) using the wing nut (3).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	485185-000	TRIPOD, MANFROTTO, 3033	1
2	485180-100	LATERAL ARM	1
3	620301-000	WING NUT	1
4	485183-000	PLATE 1,	1
5	485181-000	GUSSET	2
6	610104-000	THUMBSCREW	2
7	485182-000	BRACKET GRIP	2
8	N/A	INSTRUMENT, TRACER III	1

Figure 4-19 Installing the TRACER III-V in the tripod

4.3. Starting the Instrument

For typical operation, these are the necessary steps to start the instrument:

- If using the instruments in the battery powered mode, be sure to use fully charged batteries in the TRACER III-V, PDA, and vacuum pump for maximum battery run time. Otherwise, connect the A/C power. See section 4.1 for more information.
- Remember that for vacuum operation (examining light elements such as aluminum and titanium) the filter and clip-on window protector should be removed (see sections 4.2.1and 4.2.3). If small samples are to be analyzed in bench top mode, install the clip-on sample holder.
- If the unit is to be used in vacuum mode, connect the vacuum pump to the TRACER III-V (see section 4.2.4). **Important:** Never remove the vacuum line from the TRACER III-V without first releasing the vacuum pressure (slide the valve to the open position when sampling is complete). Start the pump and wait for the readout to display 5 torr or less.
- If desired, set up the instrument in the bench top configuration or use the tripod (see section 4.2.6).

- Install the remote trigger cable into the Lemo port on the handle of the TRACER III-V, if desired.
- Ensure that the proper card is inserted in the PDA (see section 4.2.5).
- Remove stylus from the PDA.
- Attach the PDA to the TRACER III-V:

Handheld or Tripod Configuration	Bench Top Configuration
• Unlock the PDA lock with the key. • Place PDA snugly into the cradle of the instrument. **Be careful not to use too much force installing the PDA.** This may damage the PDA connector at the base of the cradle and disable the instrument. • Lock PDA into place. The key cannot be removed until the plunger is raised.	• Insert the Null Modem cable into the Lemo port on the control panel on the TRACER III-V. • Insert the opposite end of the cable into the bottom of the PDA. • Rest the PDA in the cradle on the instrument stand.

- Turn the TRACER III-V power interlock key to the ON position. This will activate the yellow power indicator light. Wait 1-2 minutes for the Peltier cooler and X-ray tube to stabilize.
- Push PDA power ON (button on the top right side of the PDA, see section 3.2). **Important:** Do not start the PMI program until the TRACER power is ON. The PMI program is looking for communication with the TRACER. If started in the wrong sequence, refer to section 6.1 *Error: Measurement will not start* to correct the problem.

4.4. Adjusting the PDA Backlight and Starting the PMI Program

4.4.1 Adjusting the PDA Backlight

Using the backlight on the PDA while on battery power can substantially reduce battery life. To adjust the backlight on the PDA, use the stylus to:

- Tap on the “Start” icon in the upper left hand corner of the main menu of the PDA screen.
- Tap the “Settings” icon.
- Tap the “System” tab near the bottom of the screen.
- Tap “Backlight” and set according to the need.

- The “Battery Power” tab will allow the user to set the amount of time to turn off the backlight if the device is running on battery power and is not used during that specified amount of time.
- The “External Power” tab will allow the user to set the amount of time to turn off the backlight if the device is running on an external power source and is not used during that specified amount of time.
- The “Brightness” tab will allow the user to adjust the brightness level on battery or external power.
- NOTE: If the backlight has been turned off because it has not been used for the specified period of time, simply press a button or tap the screen to turn the backlight on again.

4.4.2 Starting the PMI Program

To start the PMI Program, use the stylus to:

- Tap on the “Start” icon in the upper left hand corner of the main menu of the PDA screen.
- Tap the “PMI” icon to start the analytical program. Note: It will take a few seconds to load the program.
- When the PMI program has loaded, the special Radiation Warning screen will appear as shown in figure 4-20b.

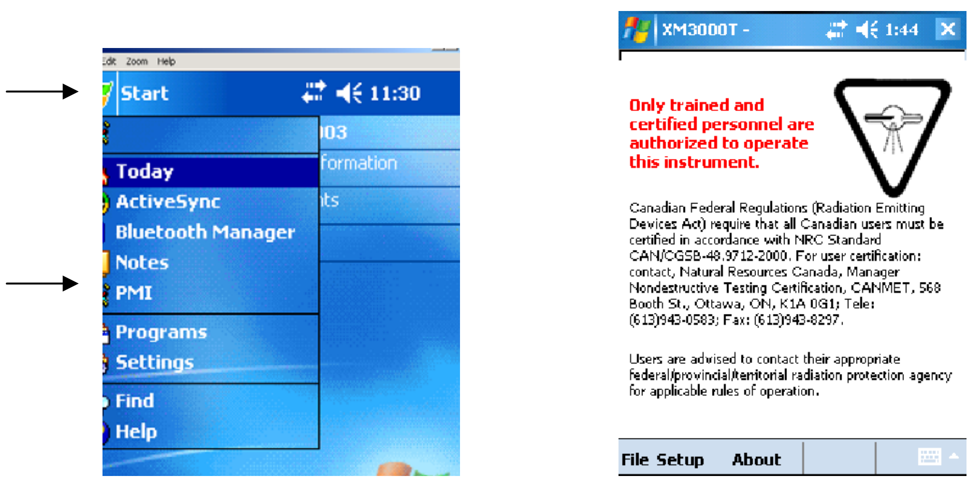


Figure 4-20 The PMI main screen

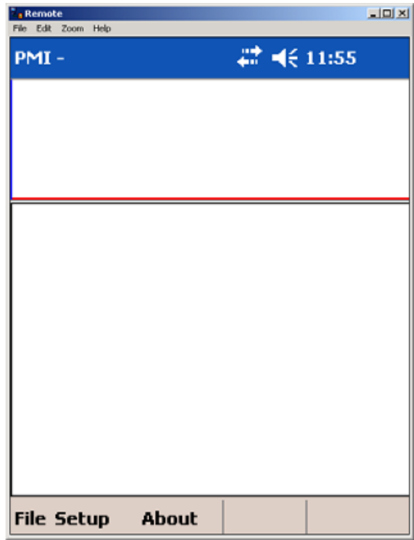


Figure 4-21 The PMI main screen

To continue, tap inside the Radiation Warning splash screen. The software will then display the main PMI screen illustrated in Figure 4.21.

To select or change specific test parameters, tap on ***Setup*** in the menu bar at the bottom of the screen. The Setup screen will open as illustrated in Figure 4.22.

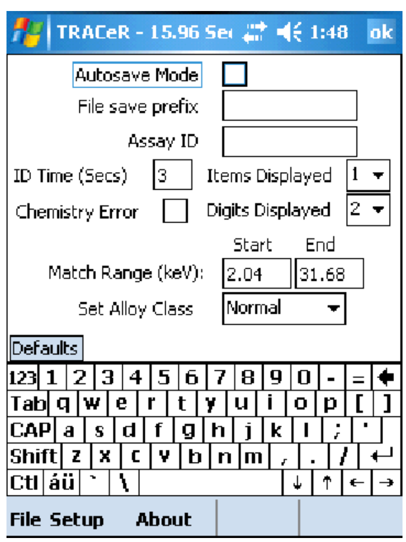


Figure 4-22 Setup screen

Setup Screen selections are as follows:

- **Autosave Mode** when selected automatically saves test results for each test run.
- **File save prefix** is used to assign file name information for a series of tests
- **Assay ID** enables the user to identify a specific assay (test) by a unique name or number.
- **ID Time** sets the amount of time after a test is started before chemistry results are displayed.
- **Items Displayed** selects the number of possible Grade IDs to display.
- **Chemistry Error** selects display of an error for each calculated element weight % which is based on counting statistics.
- **Digits Displayed** is self-explanatory.
- **Match Range (KeV)** is not changed by the user in most operation
- **Set Alloy Class** is used to select a calibration appropriate to the general alloy class of material being tested (e.g., Iron alloys, Cobalt alloys, Nickel alloys, Copper alloys, etc.)

When the appropriate selections are completed, tap on "**OK**" at the top right area of the screen to return to the main screen.

5. Daily Operation

The TRACER III-V is delivered to the user fully calibrated for a variety of alloys. Therefore, it can be used for daily work without any other preparation than that described in section 4.
The instrument is operated through the PMI analytical program. This program is located on the PDA's "Start" menu (see section 4.4.2). Using the PMI program the user can:

- Select the mode of operation
    - Default mode is *Chemistry/Grade* for analyzing aluminum, titanium, iron, nickel, cobalt, and copper alloys and obtaining the chemical composition of the sample.
    - In *Match* mode, the sample will simply be identified by its sample grade or alloy name. No chemical composition will be provided.
    - *User Library* mode is used to determine the identity and to verify alloys and grades that are not stored in memory during the factory calibration.
    - In addition, the alloy class can be changed to obtain more accurate results. For instance, to assay aluminums go to the "Setup" menu and change the "Alloy Class" from "Normal" to "Aluminum". (Be sure to remove any filters from the instrument before assaying aluminums. The Ti/Al filter should be in the instrument for assaying iron, nickel, cobalt or copper alloys.)
    - Make the measurement
    - View spectra
    - Save result and/or spectra

Saved results can be viewed by closing the PMI program and opening Pocket Excel.

5.1. Sample Preparation

The instrument analyzes the sample surface to a small depth, so the surface must be representative of the whole material.
If the sample is flat and clean (no rust, oil, dirt etc.), no sample preparation is necessary.
Contamination on the sample surface will have the greatest effect on light element analysis (Ti, V, Cr). Dust, dirt and oil can be simply cleaned from the surface with a cloth. Rust, corrosion, paint, and coatings should be removed by sanding or grinding the sample surface.

5.2. Measurement Modes

5.2.1 Chemistry/Grade

The default measurement mode is *Chemistry/Grade*. This mode is used for composition analysis of unknown samples. When measurement is started, the alloy *class* of the sample is identified (the matrix element of the sample material). The name of the closest identified alloy type, such as **SS 316,** is also reported. The *difference* value is a statistical value, which tells how close the sample being measured is to the alloy type name shown on the screen. Smaller difference values indicate that the sample correlates more closely to the reference value stored in the memory.

While the trigger is pulled, and the measurement continues, the results get more precise. After few seconds the PDA will alert the user and the assay concentrations are displayed. If the sample alloy is an alloy grade contained in the TRACER library, the TRACER will display the name of the sample. In case of a positive identification, the identified sample name is given after word “*Alloy”*. If the measured sample is slightly different from those in the factory library, the instrument will display the closest alloy preceded by “*Ref ID”*, (Reference ID). This tells you that the instrument has used the “Reference” alloy to calculate the chemistry for the current results.

Figure 5-1 Example of a chemistry analysis of a sampleMatch mode

The second measurement mode is *Match* mode. To use *Match* mode, select ”Match” from the ”File” menu in the bottom left hand corner of the screen. When match mode is selected there will be a “√ ” beside “Match” in the menu. Match mode can be used when there is no need to know the actual assay values for an unknown sample, but just identify or verify the sample grade or alloy name. The R^2 value shows the closeness of the measured sample to the reference in memory.
To exit *Match* mode (to return to *Chemistry/Grade* mode), tap “Match” from “File” menu, so that the “√ ” mark is removed from “Match”.

5.2.2 Match User library

The mode *Match User Library* is for identifying and verifying alloys and grades that are not stored in memory in factory calibration. The references included in standard factory calibration are listed in table 1.

Chemistry Library

1 Iron-27A	240 Nitronic 50-17B	241 SS 472
2 Alloy 1030-209A	241 Nitronic 60-18B	242 SS 473
3 Alloy 1040-210A	242 Greek Ascoloy	243 SS 611
4 Alloy 1045-200A	243 15-5 PH	244 SS 612
5 Alloy 1117-29C	244 17-4 PH	245 SS 613
6 Alloy 1144-199A	245 17-7 PH	246 SS 614
7 C4130	246 Alloy 20Cb3	247 SS 615
8 Alloy 4140	247 Alloy A286	248 S1Cr3
9 Alloy 4340	248 Alloy 1018-28A	249 S1Cr1
10 Alloy 4620	249 AL6XN	250 S2Cr3
11 Alloy 4820	250 Duplex 2205	251 S1Cr5
12 Alloy E6150	251 C 1/2 Mo, F1	252 S3Cr6
13 Alloy 8620	252 Maraging 300	253 S3Cr4
14 Alloy E9310	253 SS 317L	254 S2Cr7
15 Alloy E52100	254 Haynes 556	255 SS 70
16 1 1/4CR Mo	255 Invar-36	256 Ern-Zrm 291-1
17 2 1/4CRMo	256 Kovar	257 Alloy A-2
18 5CR 1/2Mo	257 Tool Steel M-2	258 Alloy D-2
19 9CR 1Mo	258 Tool Steel T-1	259 Alloy H-11
20 SS 303	259 Tool Steel A-2	260 Alloy H-12
21 SS 304	260 Tool Steel A-6	261 Alloy H-13
22 SS 309	261 Tool Steel H-13	262 Alloy L-6
23 SS 310	262 Tool Steel S-1	263 M-1
24 SS 316	263 Tool Steel S-5	264 M-2
226 SS316Ti	227 Tool Steel T-4	265 O-1
227 Alloy 321	228 NMS-100	
266 O-6		
228 Alloy 330	229 1 1/4CR Mo	267 S-1
229 Alloy 347	230 2 1/4CRMo	268 S-5
230 Alloy 410	231 9CR 1Mo	269 S-7
231 Alloy 416		270 T-1
		563 T-4
232 Alloy 420		271 BS 10V
233 Alloy 422	234 Nitronic 40	272 BS 49
234 Alloy 430	235 Hi-Mn-Stainless	273 9-4-30
235 Alloy 431	236 Ferralium 255	274 Alloy 11L17
236 Alloy 440C	237 Alloy 20 CB 3	275 Alloy 12L14
233 SS440F Se	237 Alloy 446-	238 S2Cr2
238 Custom 450	239 SS 469	276 41L40
239 Custom 455	240 SS 470	278 4140 + Bi
240 Nitronic 40	241 SS 471	277 41L50

Table 5-1. Reference library

Chemistry Library

279	4150 + Bi	317	Hastelloy B-2	355	C64200
280	8620 + Bi	318	Alloy C-22	356	C65500
281	2507	319	Alloy C-276	357	C67500
282	Stellite 6B	320	Alloy G-30	358	C70600
283	Stellite 25	321	Alloy X	359	C71500
284	Stellite 188	322	MP35N	360	C83600
285	F-75	323	Alloy 263	361	C85700
286	Ultimet 1233	324	Alloy 600-1	362	C86300
287	CCM	325	Alloy 617	363	C90300
288	Stellite 25	326	Alloy 690	364	C92200
289	Rene 41	327	Alloy 825	365	C93200
290		328	Alloy 925	366	C93700
291	14943	329	Alloy B-2	367	C95400
292	14937	330	Alloy C-22	368	C95500
293	14941	331	Alloy G-30	369	CDA 875
				570	CDA 314
294	14936	332	Alloy X	370	NARLOY-Z
295	12670	333	Nimonic 901	371	C89320
296	12672	334	9014	372	C706
297	12667	335	9015	373	CK1
298	Stellite 3	336	213 X 200 M6	374	CK2
299	81601	337	213X 200 M4	375	CK3
300	Stellite 6	338	213 X 200 M2	376	CK4
301	Nickel 200	339	22X 9012	377	CK5
302	Alloy 400	340	22X 751	378	CK6
303	Alloy R405	341	22X 802	379	Gun metal 4
304	Alloy 500	342	22X 808	380	Gun metal 5
305	Alloy 600	343	Nimonic 263	381	Gun metal 7
306	Alloy 625	344	C11000	382	Gun metal 8
307	Alloy 690	345	C17200	383	Gun metal 7131
308	Alloy 718	346	C31400	384	Gun metal 7133
309	Alloy 750	347	C36000	385	Gun metal 7132
310	Alloy 800	348	C46400	386	C71.34-3
311	Alloy 825	349	C48200	223	Hastelloy N
312	Alloy 909	350	C48500	224	Hastelloy G-3
313	Haynes 230	351	C51000	225	Hastelloy C-4
314	Haynes 242	352	C54400		
315	RA 333-60A	353	C62300		
316	Wasplaloy	354	C63000		

Table 5- 1. Reference library (continued)

5.2.2.1. Using the Match User library

From the **"**File**"** menu in the bottom left hand corner, select **"**User Library**".**
To exit *Match User Library* mode (to return to *Chemistry/Grade* mode), tap "Match" on the "File" menu, so that there is no "√" beside "Match" or "User Library".
To view the list of references saved by user, exit TRACER III-V program and tap "Start". Next tap "Programs" and open "File Explorer".
The references are on "User Lib" file (My Device / Storage Card / My Documents).
To delete a reference from the list, highlight the name of the alloy while holding the stylus on the word(s). A pop-up menu gives the option to delete the reference.

5.2.2.2. Adding Alloys to the Match User Library

Go to the "Setup" menu in the lower left hand corner of the screen and select the energy range (in keV) for the elements of interest. (NOTE: It is best to focus on as narrow of a range as possible.) If the energy range is unknown, select "Default." Tap "OK" to exit this screen.
From "File" menu in the lower left hand corner of the screen, select "Library" and "Run Timed Assay". At the prompt, enter the desired assay time in seconds (a minimum of 120 seconds is recommended) and tap "OK".

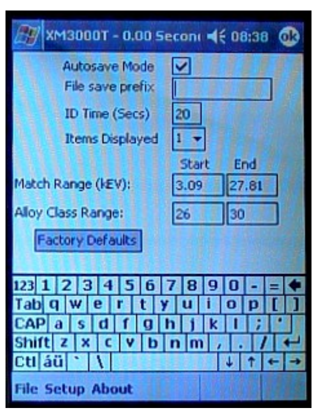


Figure 5-2 The setup menu

Place the sample on the instrument nose ensuring that it covers the IR sensor, then pull the trigger and keep the trigger pulled until the time countdown is complete. Upon completion, enter a name for the sample ("Save as") at the prompt.

5.3. Making Measurements

To analyze a sample, ensure the PMI program is running on the PDA, and then place the TRACER's nose on the sample and pull the trigger. Note: the instrument should warm up for 1-2 minutes after switching on the power before pulling the trigger in order to allow the Peltier cooler and the x-ray tube to stabilize.

IMPORTANT:

- **High intensity x-rays are generated when the trigger is pulled. Keep eyes and other body parts away from the nose of the instrument. Only trained operators may use this instrument.**
- Be sure that the infrared (IR) sensor on the nose of the instrument is against the sample (covered) or the measurement will not start. The infrared safety sensor on the instrument nose operates by detecting light reflected from the sample surface. It is designed to prevent accidental x-ray activation while moving between samples.

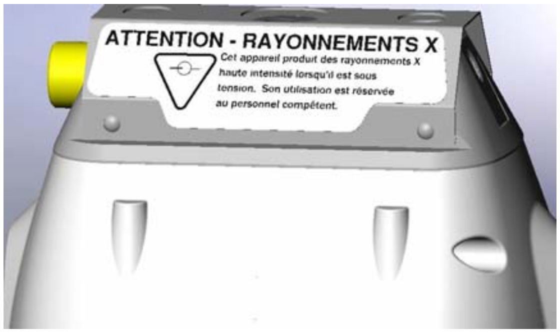


Figure 5-3 The nose of the instrument

- There are two indicator lights on the control panel of the instrument. The yellow light indicates the power is on, or, if it is blinking, that an error has occurred (see section 6.4 for troubleshooting). The red light indicates that the X-ray tube is generating x-rays (trigger is pulled). Note that if the red light looks uneven, one of the dual red lights may be out and x-rays will not be generated (see section 6.5 to troubleshoot the problem).

Figure 5-4 The control panel on the instrument

The first result is displayed after few seconds. The result is updated continuously as the trigger is pulled and the elapsed measurement time is shown in the upper left hand corner of the PDA screen. To stop the measurement, release the trigger. Note: Increasing measurement time will improve the precision of the measurement. The increased precision means the deviation of the analytical results when repeat measurements are made on the same sample will decrease. A simple rule of thumb is: Increasing measurement time by four, doubles the precision of the chemistry.
When the measurement is completed and results are shown, a new measurement can be started simply by pressing the trigger.

5.4. Saving Results

There are two ways for saving the measurement results. When using the *autosave mode*, measured results are saved automatically. The other way is to save results individually after each assay.

5.4.1 Autosave Mode

To turn the "Autosave" mode on:

- Tap the "Setup" button on the lower left of the screen.
- Select "Autosave Mode"
- Enter a File Save Prefix. (All files saved will be saved with this name prefix.)

Files stored in the Autosave mode are automatically saved in two formats: "pxl" (Pocket Excel files which can be read by PDA) and "csv" (Comma Separated Values files which can be read by Microsoft Excel on a PC).

5.4.2 Saving Individual Results

To save the current result on the screen, select “File” then “Save.” Select “Save Results” (results saved include the alloy Grade ID and its chemistry), “Save Spectra,” “Save Both,” or “Save Lib Assay.” A window will appear asking the user to enter the name of the file.

5.5. Changing Screen / Viewing modes

The default screen is the “Split screen” showing both the spectra and chemistry result. To view either the spectra or chemistry in full screen, simply tap the upper or lower portion of the screen twice. To return to the split screen mode, tap the screen twice again.

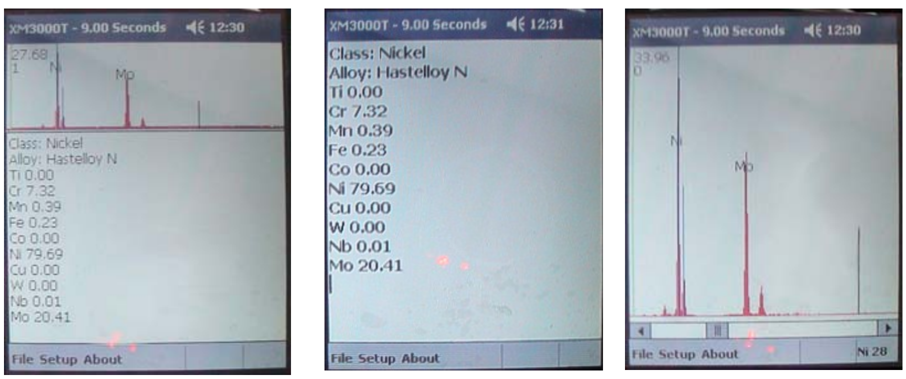


Figure 5-5 $Examples of the split screen chemistry screen and spectra screen

To examine the analyzed sample spectrum, go to full screen spectrum mode (by tapping the upper screen twice, if you are in split screen mode). To identify a peak in spectrum, click on the peak of interest. The energy for the selected peak will be displayed in the upper left corner. Now move the slider bar at the bottom of the screen until the Element ID indicator in the bottom right hand corner corresponds with the energy shown in the upper left corner.
The blue lines indicate K-line energies and the green lines indicate L-line energies. For example, if the energy in the upper left corner were *6.4* then you would move the slider bar until the “Fe-26” indicator was displayed in the bottom left corner of the screen (reference Appendix 1: Energies of K and L lines). Once the desired element ID is shown in the bottom left, tap on it and that label will be placed on the spectrum.

5.6. To turn off the instrument

- Tap the “File” button on the lower left screen and select “Exit” to exit the PMI analysis program.

- Turn the PDA power off.
- Turn the TRACER III-V power key to "OFF" position.
- If using the instrument in vacuum mode, turn off the vacuum pump. Open the vacuum release valve and allow the pressure to stabilize prior to removing the pump or tubing from the TRACER III-V (see section 4.2.4). IMPORTANT: FAILURE TO OPEN THE VACUUM RELEASE VALVE PRIOR TO REMOVING THE VACUUM TUBING FROM THE VACUUM PUMP OR THE INSTRUMENT WILL DAMAGE THE HIGHLY SENSITIVE SI-PIN DETECTOR.

5.7. Viewing stored data

The inspection of stored measurements is possible either using the "Pocket Excel" in PDA computer or by downloading the data to a PC.

5.7.1 Viewing results using "Pocket Excel"

To view stored results on the PDA, close the PMI program and open Pocket Excel. Pocket Excel automatically searches the PDA for any Excel files. Tap on the desired file to open and view. Tap on the desired file to open and view.
Files are stored in "My Device/Storage Card/My Documents/Data".

5.7.2 Viewing results using external PC

In order to download data to a PC, the MS ActiveSync software must be installed on the PC. After Active Sync is installed, transferring data will similar to transferring from a floppy disk using Microsoft Windows Explorer. Note: ActiveSync must be used in order to translate the Pocket Excel files (pxl) to Comma Separated Values files (csv), which can be read by Microsoft Excel.

5.7.2.1. Installing Microsoft ActiveSync for the first time

- Connect the USB cable to the PC
- Turn on the PC and wait as it starts up
- Insert the ActiveSync CD-ROM into the computer's drive
- Follow the instructions that appear on the computer screen

5.7.2.2. To view the results

- Open the **"**ActiveSync**"** program.
- Connect as "Guest" (Do <u>not</u> create a "Partnership".)
- In the "Explorer" window, find the folder—
    - o "Mobile Device/Storage Card/My Documents/Data"
- Select the files to be downloaded.
- Copy them to your PC hard drive.

- You can now open Excel on the PC.
- In Excel, select "File," "Open," and in the *Files of Type* drop down box select "Text Files" or "csv".

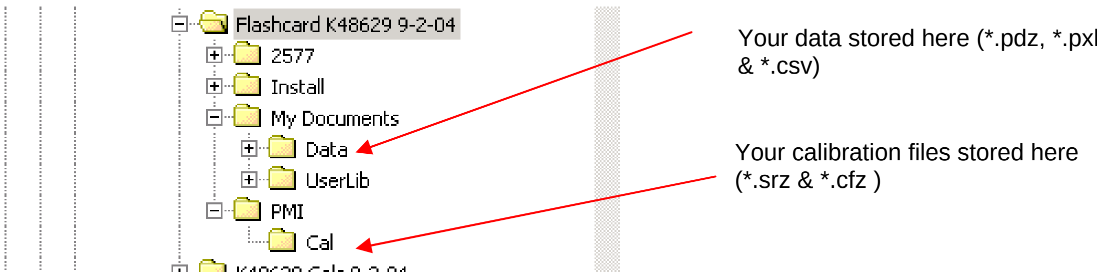


Figure 5-6 Example file explorer

5.8. Checking Calibrations

In the document envelope that was received with the instrument, there is

- A calibration sheet for stainless steel duplex 2205
- A calibration sheet for aluminum 2024
- A stainless steel duplex 2205 check sample (used to verify non-vacuum alloy calibration)
- An aluminum 2024 check sample (used to verify the vacuum/aluminum calibration)
- A CD with a copy of the calibration files

All TRACER XRF instruments are calibrated with NIST traceable alloy standards, unless the client application is for not for alloys.

To verify the calibration of the instrument, set up the instrument to operate in the appropriate configuration (see section 4) and run five 30-second assays. Average the results and the chemistry results for each element should be within the tolerance range specified on the corresponding calibration sheet.

6. Troubleshooting

6.1. Error: measurement will not start

If the PMI program is started before the instrument power key is turned on, the program will not respond to the spectral data. In this case--

- Exit the PMI program and turn off PDA and instrument power (section 5.6)
- Remove the compact flashcard (CF CARD) from the PDA (section 4.2.5).
- Press the *reset* button.
- Reinsert the flashcard and remount the PDA onto the instrument.
- Make sure the instrument power is switched on before starting PMI program.

To prevent this error state, it is important to remember to exit the PMI program before switching off the instrument power.

6.2. Can’t find the PMI program on the “Start” menu

It may take a moment for the PDA to read the compact flashcard. Tap somewhere else in the screen to get out of the “Start” menu and wait a few more seconds. Tap “Start” again and see if the PMI program pops up on the menu.

If the PMI program still does not appear on the drop down menu, turn off the PDA and ensure that the compact flashcard is inserted properly. Do not force the card into the PDA. See section 4.2.5 or the operations manual for the PDA for proper installation of the compact flashcard.

6.3. The PMI program on the PDA “locks up”

If other programs are running, the PMI program may “lock up” and fail to respond to commands. Closing other programs frees system memory for other tasks.

- Tap the “Start” menu and go to the “Settings”.
- Choose the “System” tab.
- Click on the “Memory” icon and select “Running Programs” and close all running programs except “Menu”.

The vacuum pump will not reach 5 torr or less

Ensure that the fittings on the tubing are fully inserted onto the vacuum pump and TRACER III-V and that the vacuum release port is in the closed position. See section 4.2.4 on proper installation of the vacuum pump.

IMPORTANT: FAILURE TO OPEN THE VACUUM RELEASE VALVE PRIOR TO REMOVING THE VACUUM TUBING FROM THE VACUUM PUMP OR THE INSTRUMENT WILL DAMAGE THE HIGHLY SENSITIVE SI-PIN DETECTOR.

If there continue to be problems with the vacuum level, ensure that the vacuum window is completely sealed and not punctured. See section 4.2.2 for instructions on replacing the vacuum window.

6.4. The yellow light on the control panel is blinking

The yellow light on the control panel may blink due to several errors including:

- Battery/Temperature Warning
- High Danger Shut Down Not Permitted

Turn off the PDA and instrument power (section 5.6). Allow the unit to cool to operating temperatures (-10C to +50C). Turn the instrument on again and verify that the error has been reset (yellow light no longer blinking). If the yellow light continues to blink, refer to the warranty information on how to return the instrument for evaluation.

6.5. The red light on the control panel does not turn on

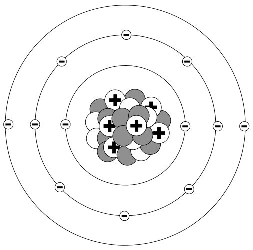
If the red light on the control panel does not turn on when taking a measurement, it is likely that the IR sensor has not been covered appropriately or is focused on a black surface. As a safety measure, if the IR sensor is not covered, the X-rays will not be generated when the trigger is pulled and no results will be displayed. DO NOT attempt to look into the nose of the instrument to see if X-rays are being generated. The IR sensor can not detect a black surface and the instrument will, therefore, not generate X-rays. Be sure that the IR sensor is fully covered and that it is focused on a colored surface.

6.6. The red light on the control panel looks uneven or dim

If the red light on the control panel looks uneven or dim, it means that one of the red LEDs is not functioning (there are 2 red LEDs in this socket). As a safety measure, if one or both of the red LEDs is not functioning, the X-rays will not be generated when the trigger is pulled and no results will be displayed. DO NOT attempt to look into the nose of the instrument to see if X-rays are being generated. Refer to the warranty information on how to return the instrument for evaluation.

APPENDIX A: BASIC RADIATION SAFETY INFORMATION

A.1 What is Radiation?



- The term radiation is used with all forms of energy - light, X-rays, radar, microwaves, and more. For the purpose of this manual, however, radiation refers to invisible waves or particles of energy from radioactive sources or X-ray tubes.
- **High levels of radiation may pose a danger to living tissue because it has the potential to damage and/or alter the chemical structure of cells. This could result in various levels of illness (i.e. mild to severe).**

- This section of the manual provides a basic understanding of radiation characteristics. This should help in preventing unnecessary radiation exposure to TRACER III-V users and persons nearby. The concepts have been simplified to give a basic picture of what radiation is and how it applies to operators of the Bruker XRF Analyzer.
- Section 2.2, "Specific Bruker TRACER III-V User Requirements" characterizes the TRACER III-V safety features and controls and provides specific radiation profiles for the user's TRACER III-V analyzer.

A.2 The Composition of Matter

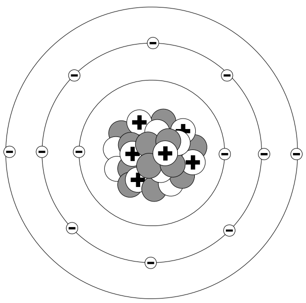


Figure A-1: An Atom

- To help understand radiation, we'll start by briefly discussing the composition of matter.
- The physical world is composed of key materials called ***elements***. The basic unit of every element is the ***atom***. Although microscopic, each atom has all the chemical characteristics of its element.

All substances or materials are made from atoms of different elements combined together in specific patterns. That is why atoms are called the basic building blocks of matter.

Example: Oxygen and hydrogen are two very common elements. If we combine one atom of oxygen and two atoms of hydrogen, the result is a molecule of H_2O, or water.

A.2.1 Parts of the Atom

Just as all things are composed of atoms, atoms are made up of three basic particles called ***protons***, ***neutrons***, and ***electrons***. Together, these particles determine the properties, electrical charge, and stability of an atom.

Protons

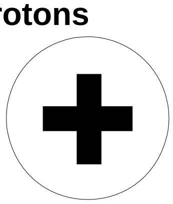


Figure A-2: A Proton

- Are found in the nucleus of the atom.
- Have a positive electrical charge.
- Determine the atomic number of the element, therefore, if the number of protons in the nucleus changes, the element changes.

Neutrons

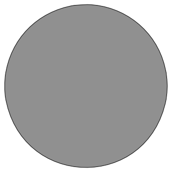


Figure A-3: A Neutron

- Are found in the nucleus of the atom.
- Have no electrical charge.
- Help determine the stability of the nucleus.
- Are in the nucleus of every atom except Hydrogen (H-1).
- Atoms of the same element have the same number of protons, but can have a different number of neutrons.

Electrons

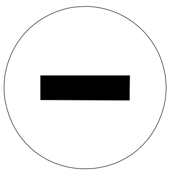


Figure A-4: An Electron

- Are found orbiting around the nucleus at set energy levels or shells (K and L shells are important in X-ray fluorescence).
- Have a negative electrical charge.
- Determine chemical properties of an atom.
- Have very little mass.

A.2.2 Structure of the Atom

The design or atomic structure of the atom has two main parts: The ***nucleus*** and the ***electron shells*** that surround the nucleus.

Nucleus

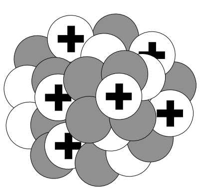


Figure A-5: The Nucleus

- Is the center of an atom.
- Is composed of protons and neutrons.
- Produces a positive electrical field.
- Makes up nearly the entire mass of the atom.

Electron Shells

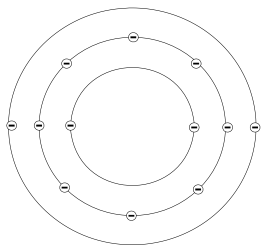


Figure A-6: Electron Shells

- Circle the nucleus of an atom in a prescribed orbit.
- Have a specific number of electrons.
- Produce a negative electrical field.
- Are the principle controls in chemical reactions.

The protons and neutrons that form the nucleus are bound tightly together by powerful nuclear forces. Electrons (-) are held in orbit by their electromagnetic attraction to the protons (+). When these ratios become unbalanced, the electrical charge and stability of the atom are affected.

A.3 Electrical Charge of the Atom

The ratio of protons and electrons determine whether the atom has a positive, negative, or neutral electrical charge. The term ion is used to define atoms or groups of atoms that have a positive or negative electrical charge.

Positive Charge (+)—If an atom has **more protons** than electrons, the charge is positive.

Negative Charge (-)—If an atom has **more electrons** than protons, the charge is negative.

Neutral (No Charge)—If an atom has an **equal number** of protons and electrons, it is neutral, or has no net electrical charge.

An atom's charge is important because it determines whether the atom is capable of chemical reactions. The process of removing electrons from a neutral atom is called ***ionization***.

Atoms that develop a positive or negative charge (gain or lose electrons) are called ***ions***. When an electrically neutral atom loses an electron, that electron and the now positively charged atom are called an ***ion pair***.

A.4 The Stability of the Atom

The concept of stability of an atom is related to the structure and the behavior of the nucleus:

Every stable atom has a nucleus with a specific combination of neutrons and protons.

Any other combination results in a nucleus that has too much energy to remain stable.

Unstable atoms try to become stable by releasing excess energy in the form of particles or waves (radiation).

The process of unstable atoms releasing excess energy is called ***radioactivity***.

A.5 Radiation Terminology

Before examining the subject of radiation in more detail, there are several important terms to be reviewed and understood.

Bremsstrahlung: The X-rays or "braking" radiation produced by the deceleration of electrons, namely in an X-ray tube.

Characteristic X-rays: X-rays emitted from electrons during electron shell transfers.

Fail-Safe Design: One in which all failures of indicator or safety components that can reasonably be anticipated cause the equipment to fail in a mode such that personnel are safe from exposure to radiation. For example, if the red lamp indicating "X-RAY ON" fails, the production of X-rays shall be prevented.

Ion: An atom that has lost or gained an electron.

Ion Pair: A free electron and positively charged atom.

Ionization: The process of removing electrons from the shells of neutral atoms.

Ionizing Radiation: Radiation that has enough energy to remove electrons from neutral atoms.

Isotope: Atoms of the same element that have a different number of neutrons in the nucleus.

Non-ionizing Radiation: Radiation that does not have enough energy to remove electrons from neutral atoms.

Normal Operation: Operation under conditions suitable for collecting data as recommended by manufacturer, including shielding and barriers.

Primary Beam: Ionizing radiation from an X-ray tube that is directed through an aperture in the radiation source housing for use in conducting X-ray fluorescence measurements.

Radiation: The energy in transit in form of electromagnetic waves or particles.

Radiation Generating Machine: A device that generates X-rays by accelerating electrons, which strike an anode.

Radiation Source: An X-ray tube or radioactive isotope.

Radiation Source Housing: That portion of an X-ray fluorescence (XRF) system, which contains the X-ray tube or radioactive isotope.

Radioactive Material: Any material or substance that has unstable atoms, which are emitting radiation.

System Barrier: That portion of an area, which clearly defines the transition from a controlled area to a radiation area and provides the necessary shielding to limit the dose rate in the controlled area during normal operation.

X-ray Generator: That portion of an X-ray system that provides the accelerating voltage and current for the X-ray tube.

X-ray System: Apparatus for generating and using ionizing radiation, including all X-ray accessory apparatus, such as accelerating voltage and current for the X-ray tube and any needed shielding.

A.6 Types of Radiation

As stated earlier, radiation consists of invisible waves or particles of energy that can have a health effect on humans if received in too large a quantity. There are two distinct types of radiation: ***non-ionizing*** and ***ionizing***.

Non-ionizing Radiation

Non-ionizing radiation does not have the energy needed to ionize an atom (i.e. to remove electrons from neutral atoms).

Sources of non-ionizing radiation include light, microwaves, power lines, and radar.

Although this type of radiation can cause biological damage, like sunburn, it is generally considered less hazardous than ionizing radiation.

Ionizing Radiation

Ionizing radiation does have enough energy to remove electrons from neutral atoms. **Ionizing radiation is of concern due to its potential to alter the chemical structure of living cells.** These changes can alter or impair the normal functions of a cell. Sufficient amounts of ionizing radiation can cause hair loss, blood changes, and varying degrees of illness. These

levels are approximately 1,000 times higher than levels that the public or workers are permitted to receive.

There are four basic types of ionizing radiation as shown below: These are emitted from different parts of an atom (Figure A-7).

Alpha Particles

Beta Particles

Gamma rays or X-rays

Neutron Particles

Note: TRACER III-V XRF devices only emit X-rays

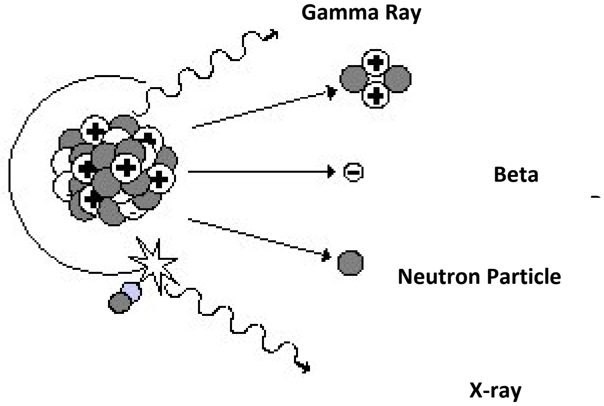


Figure A-7: Types of Ionizing Radiation

The penetrating power for each of the four basic radiations varies significantly (see Figure A-8).

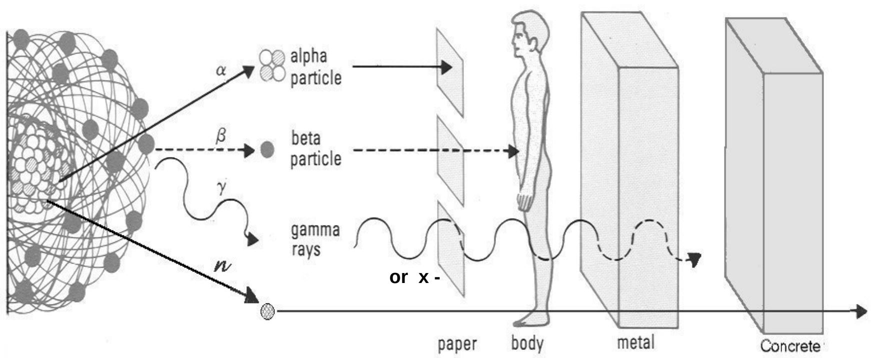


Figure A-8: The Penetrating Power of Various Types of Radiation

Alpha particles

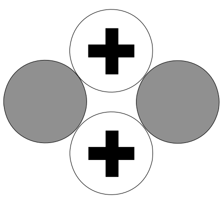


Figure 9:
Alpha Particle

- Have a large mass, consisting of two protons and two neutrons.
- Have a positive charge and are emitted from the nucleus.
- Ionize by stripping away electrons (-) from other atoms with its positive (+) charge.

Range: Due to the large mass and charge, alpha particles will only travel about one to two inches in air. This also limits its penetrating ability.

Shielding: Most alpha particles will be stopped by a piece of paper, several centimeters of air, or the outer layer (i.e. dead layer) of the skin.

Hazard: Due to limited range and penetration ability, alpha particles are not considered an external radiation hazard. However, if inhaled or ingested, alpha radiation is a potent internal hazard as it can deposit large amounts of concentrated energy in small volumes of body tissue.

Beta Particles

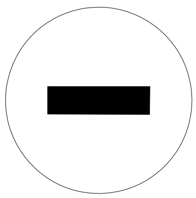


Figure 10: A Beta Particle

- Have a small mass and a negative charge (-), similar to an electron.
- Are emitted from the nucleus of an atom.
- Ionize other atoms by stripping electrons out of their orbits with their negative charge.

Range: Small mass and negative charge give the beta particle a range of about 10 feet in air. The negative charge limits penetrating ability.

Shielding: Most beta particles can be stopped by a few millimeters of plastic, glass, or metal foil, depending on the density of the material.

Hazard: Although beta particles have a fairly short range, they are still considered an external radiation hazard, particularly to the skin and eyes. If ingested or inhaled, beta radiation may pose a hazard to internal tissues.

Gamma Rays and X-rays

Gamma rays and X-rays are electromagnetic waves or photons of pure energy that have no mass or electrical charge. Gamma rays and X-rays:

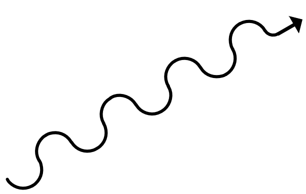


Figure 11:
A Gamma or X-ray

- Are identical except that gamma rays come from the nucleus, while X-rays come from the electron shells or from an X-ray generating machine
- Ionize atoms by interacting with electrons.

Range: Because gamma and X-rays have no charge or mass, they are highly penetrating and can travel quite far. Range in air can be easily several hundred feet.

Shielding: Gamma and X-rays are best shielded by use of dense materials, such as concrete, lead, or steel.

Hazard: Due to their range and penetrating ability, gamma and X-ray radiation are considered primarily an external hazard.

Neutron Particles

Neutron radiation consists of neutrons that are ejected from the nucleus of an atom. Neutron particles:

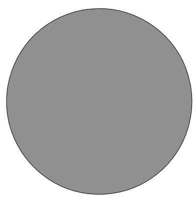


Figure 12: A Neutron

- Are produced during the normal operation of a nuclear reactor or particle accelerator, as well as the natural decay process of some radioactive elements.
- Can split atoms by colliding with their nuclei, forming two or more unstable atoms. This is called fission. These atoms then may cause ionization as they try to become stable.
- Neutrons can also be absorbed by some atoms (capture) without causing fission resulting in creation of a sometimes radioactive atom dependent on the absorber. This is called fusion.

Range: Since neutrons have no electrical charge, they have a high penetrating ability and require thick shielding material to stop. Range in air can be several hundred feet.

Shielding: The best materials to shield against neutron radiation are those with high hydrogen content (water, concrete or plastic).

Hazard: Neutron radiation is considered primarily an external hazard due to its range and penetrating ability.

A.7 Units for Measuring Radiation

The absorption of radiation into the body, or anything else, depends upon two things: the type of radiation involved and the amount of radiation energy received. The units for measuring radiation internationally are the ***Gray*** and ***Sievert*** and in the USA are the ***rad*** and ***rem***.

A.7.1 Rad (Radiation Absorbed Dose)

A rad is:

A unit for measuring the amount of radiation energy absorbed by a material (i.e. dose).

Defined for any material (e.g. 100 ergs/gm).

Applied to all types of radiation.

Not related to biological effects of radiation in the body.

1 rad = 1000 millirad (mrad)

The Gray (Gy) is the System International (SI) unit for absorbed energy.

1 rad = 0.01 Gray (Gy) and 1 Gray = 100 rad.

A.7.2 Rem

Actual biological damage depends upon the concentration as well as the amount of radiation energy deposited in the body. The rem is used to quantify overall doses of radiation, their ability to cause damage, and their dose equivalence (see below).

A rem is:

Is a unit for measuring dose equivalence.

Is the most commonly used unit of radiation exposure measure.

Pertains directly to humans.

Takes into account the energy absorbed (dose); the quality of radiation; the biological effect of different types of radiation in the body and any other factor. For gamma and X-ray radiation all of these factors are unity so that for these purposes a rad and a rem are equal.

Sievert is the SI unit for dose equivalence.

1 rem = 1000 millirem (**mrem**)

1 rem = 0.01 Sievert (**Sv**) and 1Sv = 100 rem

A.7.3 Dose and Dose Rate

Dose is the amount of radiation you receive during any exposure.

Dose Rate is the rate at which you receive the dose.

Example: 1) Dose rate = dose/time = mrem/hr

2) Dose = dose rate x time = mrem

A.8 Sources of Radiation

We live in an environment which is and has always been subject to radiation. As human beings, we have evolved in the presence of ionizing radiation from natural background radiation.

No one can completely avoid exposure to radiation, whether working with radioactive materials or not. We are continually exposed to sources of radiation from our environment, both natural and man-made.

The average person in the U.S. receives about 3.6 mSv or 360 mrem of radiation per year. The average annual radiation dose in the state of Colorado is 4.5 – 5.0 mSv (450 – 500 mrem) per year.

A.8.1 Natural Sources

Most of our radiation exposure comes from natural sources (about 3.0 mSv or 300 mrem per year). In fact, most of the world's population will be exposed to more ionizing radiation from natural sources than they will ever receive on the job.

There are several sources of natural background radiation. The radiation from these sources is exactly the same as that from man-made sources.

The four major sources of natural radiation include:

Cosmic Radiation

Terrestrial Radiation (sources in the earth's crust)

Sources (sources in the human body such as K-40 from, e.g., eating bananas) also referred to as internal sources.

Radon, Uranium and Thorium.

Cosmic Radiation

Comes from the sun and outer space.

Is composed of positively charged particles and gamma radiation.

Increases in intensity at higher altitudes because there is less atmospheric shielding.

Example: The population of Denver, Colorado, receives twice the radiation exposure from cosmic rays as people living at sea level

The average dose received by the general public from cosmic radiation is approximately 280 µSv (28 mrem) per year.

Terrestrial Radiation

There are natural sources of radiation in the soil, rocks, building materials, and drinking water. Some of the contributors to these sources include naturally radioactive elements such as Radium, Uranium, and Thorium. Many areas have elevated levels of terrestrial radiation due to increased concentrations of Uranium or Thorium in the soil. The average dose received by the general public from terrestrial radiation is about 280 µSv (28 mrem) per year.

Internal Sources

The food we eat and the water we drink all contain some trace amount of natural radioactive materials. These naturally occurring radioactive isotopes include Na-24, C-14, Ar-41 and K-40. Most of our internal exposure comes from K-40

There are four ways to receive internal exposure:

Breathing

Swallowing (ingestion)

Absorption through the skin

Wounds (breaks in the skin)

The average dose received by the general public from internal sources is about 400 µSv (40 mrem) per year.

Examples of Internal Exposure:

1) Inhalation of radon or dust from other radioactive materials
2) Potassium-40 in bananas
3) Water containing traces of uranium, radium, or thorium
4) Handling of a specified radioactive material without protective gear or with an unhealed cut

Radon

Radon comes from the radioactive decay of radium, which is naturally present in soil. Radon and its decay products are present in the air, and when inhaled can cause a dose to the lung.

Is a gas, which can travel through soil and collect in basements or other areas of the home.

Emits alpha radiation. Because alpha radiation cannot penetrate the **outer** layer of skin on a human body, it presents a hazard only if ingested into the body.

Is the largest contributor of natural occurring radiation.

A.8.2 Man-made Sources

In addition to natural background radiation, some exposure comes from man-made sources that are part of our everyday lives. These sources account for the remaining approximately 65 mrem (650 µSv) per year of the average annual radiation dose.

The four major sources of man-made radiation exposures are:

Medical radiation (approximately 53 mrem, or 530 µSv per year)

Atmospheric testing of nuclear weapons (less than 1 mrem, or 10 µSv, per year)

Consumer products (approximately 10 mrem, or 100 µSv, per year)

Industrial uses (less than 3 mrem, or 30 µSv, per year)

Medical Radiation

Medical radiation involves exposure from medical procedures such as X-rays (chest, dental, etc.), CAT scans, and radiotherapy. The typical dose received from a single chest X-ray is about 10 mrem, or 100 µSv, per exposure.

Radioactive sources used in medicine for diagnosis and therapy result in an annual average dose to the general population of 14 mrem, or 140 µSv.

The average dose received by the general public from all medical procedures is about 53 mrem, or 530 µSv, per year.

Atmospheric Testing of Nuclear Weapons

Testing of nuclear weapons during the 1950s and early 1960s resulted in fallout of radioactive materials. This practice is now banned by most nations.

The average dose received by the general public from residual fallout is approximately 1 mrem, or 10 µSv, per year.

Consumer Products

These include such products as:

- Televisions
- Building materials
- Combustible fuels
- Smoke detectors
- Camera lenses
- Welding rods

The total average dose received by the general public from all these products is about 10 mrem, or 100 µSv, per year.

Industrial uses

Industrial uses include X-ray generating machines used to test all sorts of welds, material integrity, bore holes, and to perform microscopic analyses of materials.

The average dose received by the general public from industrial uses is less than 1 mrem, or 10 µSv, per year.

Table A-1: Example of Annual Radiation Doses from Selected Sources*

Exposure	µSv	mrem
Cigarette Smoking	13000	1300
Radon in homes	2000	200
Medical exposures	530	53
Terrestrial radiation	300	30
Cosmic radiation	300	30
Round trip US by air	50	5
Building materials	36	3.6
World wide fallout	<10	<1
Natural gas range	2	0.2
Smoke detectors	0.001	0.0001

Table A-2: Average Annual Occupational Doses*

Occupation	mSv	mrem
Airline flight crewmember	10	1000
Nuclear power plant worker	7	700
Grand central station worker	1.2	120
Medical personnel	0.7	70
DOE/DOE contractors	0.44	44

* Based on U.S. data only

Significant Doses

As stated previously, the general public is exposed daily to small amounts of radiation. However, there are four major groups of people that have been exposed in the past to significant levels of radiation. Because of this we know much about ionizing radiation and its biological effects on the body.

These four major groups of people who have been exposed to significant levels of radiation are:

The earliest radiation workers, such as radiologists, who received large doses of radiation before biological effects were recognized. Since then, safety standards have been developed to protect such employees.

The more than 100,000 people who survived the atomic bombs dropped on Hiroshima and Nagasaki.

Those involved in radiation accidents, like Chernobyl.

People who have received radiation therapy for cancer. This is the largest group of people to receive significant doses of radiation.

A.9 Biological Effects of Radiation

A.9.1 Cell Sensitivity

The human body is composed of billions of living cells. Groups of these cells make up tissues, which in turn make up the body's organs. Some cells are more resistant to viruses, poisons, and physical damage than others. The most sensitive cells are those that are rapidly dividing, that is why exposure to a fetus is so carefully controlled. Radiation damage may depend on both resistance and level of activity during exposure.

A.9.2 Acute and Chronic Doses of Radiation

All radiation, if received in sufficient quantities, can damage living tissue. The key lies in how much and how quickly a radiation dose is received. Doses of radiation fall into one of two categories: ***acute*** or ***chronic***.

Acute Dose

An acute dose is a large dose of radiation received in a short period of time that results in physical reactions due to massive cell damage (acute effects). The body can't replace or repair cells fast enough to undo the damage right away, so the individual may remain ill for a long period of time. Acute doses of radiation can result in reduced blood count and hair loss.

Recorded whole body doses of 100 - 250 mSv (10 - 25 rem) have resulted only in slight blood changes with no other apparent effects.

Radiation Sickness

Radiation sickness occurs at acute doses greater than 1 Sv (100 rem.) Radiation therapy patients often experience it as a side effect of high-level exposures to singular areas. Radiation sickness may cause nausea (from cell damage to the intestinal lining), and additional symptoms such as fatigue, vomiting, increased temperature, and reduced white blood cell count.

Acute Dose to the Whole Body

Recovery from an acute dose to the whole body may require a number of months. Whole body doses of 5 Sv (500 rem) or more may result in damage too great for the body to recover.

Example: 30 firefighters at the Chernobyl facility lost their lives as a result of severe burns and acute radiation doses exceeding 8 Sv (800 rem.)

Only extreme cases (as mentioned above) result in doses so high that recovery is unlikely.

Acute Dose to Part of the Body

Acute dose to a part of the body most commonly occur in industry (use of X-ray machines), and often involve exposure of extremities (hand, fingers, etc.). Sufficient radiation doses may result in loss of the exposed body part. The prevention of acute doses to part of the body is one of the most important reasons for proper training of personnel.

Chronic Dose

A chronic dose is a small amount of radiation received continually over a long period of time, such as the dose of radiation we receive from natural background sources every day.

Chronic Dose vs. Acute

The body tolerates chronic doses better than acute doses because:

Only a small number of cells need repair at any one time.

The body has more time to replace dead or non-working cells with new ones.

Radical physical changes do not occur as with acute doses.

Genetic Effects

Genetic effects involve changes in chromosomes or direct irradiation of the fetus. Effects can be somatic (cancer, tumors, etc.) and may be heritable (passed on to offspring).

Somatic Effects

Somatic effects apply directly to the person exposed, where damage has occurred to the genetic material of a cell that could eventually change it to a cancer cell. It should be noted that the chance of this occurring at occupational doses is very low.

Heritable Effects

This effect applies to the offspring of the individual exposed, where damage has occurred to genetic material that doesn't affect the person exposed, but will be passed on to offspring.

To date, only plants and animals have exhibited signs of heritable effects from radiation. This data includes the 77,000 children born to the survivors of Hiroshima and Nagasaki. The studies performed followed three generations, which included these children, their children, and their grandchildren.

A.9.3 Biological Damage Factors

Biological damage factors are those factors, which directly determine how much damage living tissue receives from radiation exposure, and include:

Total dose: the larger the dose, the greater the biological effects.

Dose rate: the faster the dose is received, the less time for the cell to repair.

Type of radiation: the more energy deposited the greater the effect.

Area exposed: the more body area exposed, the greater the biological effects.

Cell sensitivity: rapidly dividing cells are the most vulnerable.

Individual sensitivity to ionizing radiation:

a) developing embryo/fetus is the most sensitive.
b) children are the second most vulnerable.
c) the elderly are more sensitive than middle-aged adults.
d) young to middle-aged adults are the least sensitive.

Prenatal Exposure

A developing embryo/fetus is the most sensitive to ionizing radiation because of its rapidly dividing cells. While no inheritable effects from radiation have yet been recorded, there have been effects seen in some children exposed to radiation while in the womb.

Possible effects include:

Slower growth

Impaired mental development

Childhood cancer

Some of the children from Hiroshima and Nagasaki, exposed to radiation while in the womb, were born with low birth weights and mental retardation. While it has been suggested that such exposures may also increase the risk of childhood cancer, this has not yet been proven. It is believed that only doses exceeding 150 mSv (15 rem) increase this risk significantly.

It should be stressed that many different physical and chemical factors can harm an unborn child. Alcohol, exposure to lead, and prolonged exposure in hot tubs are just a few of the more publicized dangers to fetal development.

For more information, see Radiation Dose Limits: Declared Pregnant Worker, Section A.8.

Putting Risks in Perspective

Acceptance of any risk is a very personal matter and requires that a person make informed judgments, weighing benefits against potential hazards.

Risk Comparison

The following summarizes the risks of radiation exposure:

The risks of low levels of radiation exposure are still unknown.

Since ionizing radiation can damage chromosomes of a cell, incomplete repair may result in the development of cancerous cells.

There have been no observed increases of cancer among individuals exposed to occupational levels of ionizing radiation.

Using other occupational risks and hazards as guidelines, nearly all scientific studies have concluded the risks of occupational radiation doses are acceptable by comparison.

Table A3: Average Lifetime Estimated Days Lost Due to Daily Activities

Activity*	Estimated Days Lost
Cigarette smoking	2250
25% Overweight	1100
Accidents (all types)	435
Alcohol consumption	365
Driving a motor vehicle	207
Medical X-rays	6
10 mSv (1 rem) Occupational Exposure	1
10 mSv (1 rem) per year for 30 years	30

Table A4: Average Estimated Days Lost By Industrial Occupations

Occupation*	Estimated Days Lost
Mining/Quarrying	328
Construction	302
Agriculture	277
Transportation/Utilities	164
Radiation dose of 50 mSv (5 rem) per yr for 50 years	250
All industry	74
Government	55
Service	47
Manufacturing	43
Trade	30

The comparison of health and industrial risks illustrates the fact that no matter what you do there is always some associated risk. For every risk there is some benefit, so you as the worker must weigh these risks and determine if the risk is worth the benefit. Exposure to ionizing radiation is a consequence of the regular use of many beneficial materials, services, and products. By learning to respect and work safely around radiation, we can effectively manage our exposure.

Note: * based on US data only.

A.10 Radiation Dose Limits

To minimize risks from the potential biological effects of radiation, regulatory agencies and authorative bodies have established radiation dose limits for occupational workers. These limits apply to those working under the provisions of a specific license or registration.

The limits described below have been developed based on information and guidance from the International Commission on Radiological Protection (ICRP-1990), the Biological Effects of Ionizing Radiation (BEIR) Committee, the US Environmental Protection Agency (EPA} and the National Council of Radiation Protection (NCRP).

For an XRF analyzer using an X-ray tube as the source, any requirement on dose limits for the operators would be established by the appropriate regulatory agency.

In general, the larger the area of the body that is exposed, the greater the biological effects for a given dose. Extremities are less sensitive than internal organs because they do not contain critical organs. That is why the annual dose limit for extremities is higher than for a whole body exposure that irradiates the internal organs.

Your employer may have additional guidelines and set administrative control levels. Each employee should be aware of such additional requirements to do their job safely and efficiently.

The following table illustrates typical dose limits.

Table A-5: Annual Occupational Dose Limits:

	International	U.S.
Whole Body	20 mSv*	5 rem
Extremities	500 mSv	50 rem
Organs or Tissue	500 mSv	50 rem
(Excluding lens of the eye and skin)		
Lens of the Eye	150 mSv	15 rem

*Averaged over 5 years

Table A-6: Radiation Limits for Visitors and Public

International Limit	1 mSv (100 mrem) per year
United States Limit	1 mSv (100 mrem) per year

Declared Pregnant Worker

A female radiation worker may inform her supervisor, in writing of her pregnancy at which time, she becomes a Declared Pregnant Worker. The employer should then provide the option of a mutually agreeable assignment of work tasks, without loss of pay or promotional opportunity, such that further radiation exposure will not exceed the dose limits as shown below for the declared pregnant worker.

Table A-7: Dose to Pregnant Worker

International Limit	2 mSv (200 mrem) to abdomen during remainder of gestation period after declaration (ICRP 60)
United States Limit	Declared Pregnant Worker (embryo/fetus) - 0.5 rem / 9 months (≈ 0.05 rem / month)

A.11 Measuring Radiation

Because we cannot detect radiation through our senses, special devices may be required by some jurisdictions for personnel operating an XRF to monitor and record the operator's exposure. These devices are commonly referred to as ***dosimeters***, and the use of them for monitoring is called ***dosimetry***.

The following information may apply to personnel using the TRACER III-V XRF analyzers in jurisdictions where dosimetry is required:

- Wear an appropriate dosimeter that can record low energy photon radiation.
- Dosimeters wear period of three months may be used, subject to local regulation.
- Each dosimeter will be assigned to a particular person and is not to be used by anyone else.

Measuring Devices

Several devices are employed for measurement of radiation doses: including ionization chambers, Geiger-Mueller tubes, pocket dosimeters, thermoluminescence devices (TLD's), optically stimulated luminescence dosimeters (OSL) and film badges. It is the responsibility of your Radiation Safety Officer (RSO) or Radiation Protection Officer (RPO) to specify and acquire the dosimetry device or devices specified by your local regulatory authority for each individual and to specify any other measuring devices to be used.

The Ionization Chamber

The Ionization Chamber is the simplest type of detector for measuring radiation.

It consists of a cylindrical chamber filled with air and an insulated wire running through its center length with a voltage applied between the wire and outside cylinder. When radiation passes through the chamber, ion pairs are extracted and build up a charge. This charge is used as a measure of the exposure received.

This measurement is not highly efficient (30-40% efficiency is typical), as some radiation may pass through the chamber without creating enough ion pairs for proper measurement.

The Geiger-Mueller Tube

The Geiger-Mueller (GM) Tube is very similar to the ion chamber, but is much more sensitive. The voltage of its static charge is so high that even a very small number of ion pairs will cause it to discharge.

A GM tube can detect and measure very small amounts of beta or gamma radiation.

The Pocket Dosimeter

The Pocket Dosimeter is also a specialized version of the ionization chamber. It is basically a quartz fiber electroscope. The chamber is given a single charge of static electricity, which it stores like a condenser. As radiation passes through the chamber, the charge is reduced in proportion to the amount of radiation received, and the indicator moves towards a neutral position.

A dosimeter that has been exposed to radiation must be periodically recharged, or zeroed.

Thermo luminescence Devices (TLDs) and Optically Simulated Luminescence Dosimeter (OSL)

TLDs and OSL are devices that use materials in the form of crystals, which can store free electrons when exposed to ionizing radiation. These electrons remain trapped until the crystals are read by a special reader or processor, using heat (TLD) or light (OSL). When this occurs, the electrons are released and the crystals produce light. The intensity of the light can be measured and related directly to the amount of radiation received.

Thermoluminescent materials, which are useful as dosimeters include: lithium fluoride, lithium borate, calcium fluoride, calcium sulfate, and aluminium oxide.

There are two common types of dosimeters: whole body and extremity.

Whole Body Dosimeter

A TLD or OSL whole body dosimeter is used to measure both shallow and deep penetrating radiation doses. It is normally worn between the neck and waist.

The measured dose recorded by this device may be used as an individual's legal occupational exposure.

Extremity

An extremity is a TLD in the shape of a ring, which is worn by workers to measure the radiation exposure to the extremities.

The measured dose recorded by this device may be used as the worker's legal occupational extremity exposure.

A.12 Reducing Exposure (ALARA Concept)

While dose limits and administrative control levels already ensure very low radiation doses, it is possible to reduce these exposures even more.

The main goal of the ALARA program is to reduce ionizing radiation doses to a level that is As Low As Reasonably Achievable (ALARA).

ALARA is designed to prevent unnecessary exposures to employees, the public, and to protect the environment. It is the responsibility of all workers, managers, and safety personnel alike to ensure that radiation doses are maintained ALARA.

There are three basic practices to maintain external radiation ALARA:

Time
Distance
Shielding

A.12.1 Time

The first method of reducing exposure is to limit the amount of time spent in a radioactive area. The shorter the time, the lower the amount of exposure.

The effect of time on radiation could be stated as:

Dose = Dose Rate x Time

This means the less time you are exposed to ionizing radiation, the smaller the dose you will receive.

Example: If 1 hour of time in an area results in 1 mSv (100 mrem) of radiation, then 1/2 an hour results in 0.5 mSv (50 mrem), 1/4 an hour would result in 0.25 mSv (25 mrem), and so on.

A.12.2 Distance

The second method for reducing exposure is by maintaining the maximum possible distance from the radiation source to the operator or member of the public.

The principle of distance is that the exposure rate is reduced as the distance from the source is increased. The greater the distance, the amount of radiation received is reduced.

This method can best be expressed by the ***Inverse Square Law***. The inverse square law states that doubling the distance from a point source reduces the dose rate (intensity) to 1/4 of the original. Tripling the distance reduces the dose rate to 1/9 of its original value.

Expressed mathematically:

$$C \times \frac{D_1^2}{D_2^2} = I$$

Variables

C is the intensity (dose rate) of the radiation source
D_1 is the distance at which C was measured
D_2 is the distance from the source
I is the new level of intensity at distance **D_2** from the source

Example: If the intensity (C) of a point source is 1 mSv (100 mrem) per hr at one foot (D_1), then at two feet (D_2) it would be 0.25 mSv (25 mrem) perhr (I).

C = 1 mSv (100 mrem) per hr
D_1 = 1 foot D_2 = 2 feet
I = 0.25 mSV (25 mrem) per hr
C x $(D_1)^2$ /$(D_2)^2$ = 1 X $(1)^2$/ $(2)^2$ = 1/4 = 0.25 mSv/hr **OR** 100 X $(1)^2$/ $(2)^2$ = 25 mrem/hr. (I)

The inverse square law does not apply to sources of greater than a 10:1 (distance: source size) ratio, or to the radiation fields produced from multiple sources.

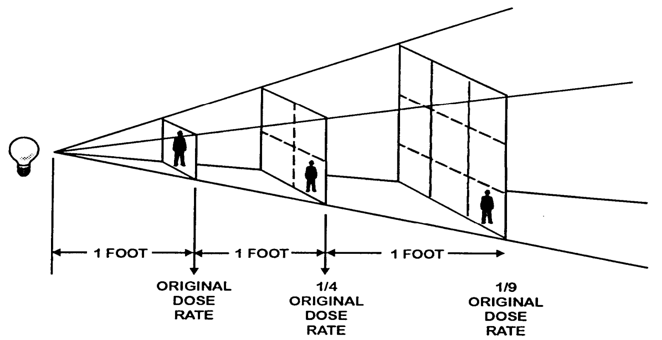


Figure A.13: The Inverse Square Law

A.12.3 Shielding

The third, and perhaps most important, method of reducing exposure is shielding.

Shielding is generally considered to be the most effective method of reducing radiation exposure, and consists of using a material to absorb or scatter the radiation emitted from a source before it reaches an individual.

As stated earlier, different materials are more effective against certain types of radiation than others. The shielding ability of a material also depends on its density, or the weight of a material per unit of volume.

Example: A cubic foot of lead is heavier than the same volume of concrete, and so it would also be a better shield.

Although shielding may provide the best protection from radiation exposure, there are still several precautions to keep in mind when using TRACER III-V XRF devices:

Persons outside the shadow cast by the shield are not necessarily 100% protected. Note: All persons not directly involved in operating the XRF should be kept at least three feet away.

A wall or partition may not be a safe shield for persons on the other side.

Scattered radiation may bounce around corners and reach nearby individuals, whether or not they are directly in line with the test location.

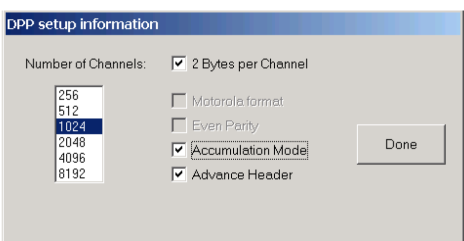
Note: The operator should ensure that there is no one on the other side of the wall when using an XRF Analyzer.

Appendix D: PXRF Spectrum Analysis Tools for the TRACER

Quantification Calibration Method

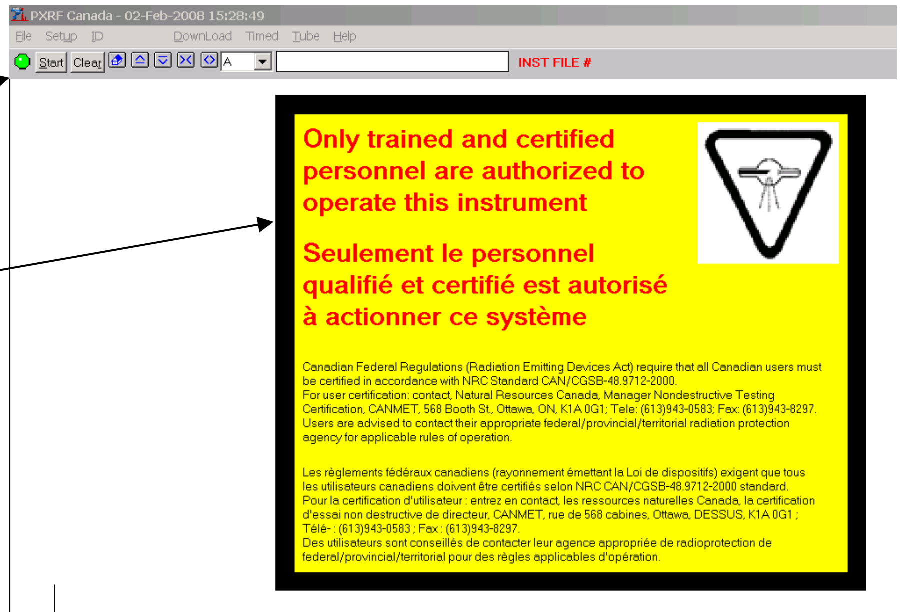
Taking Spectra

1. Take spectra to characterize the sample.
   - Open the “PXRF” Program
   - Attach the TRACER to PC via the Serial/USB cable provided. (4 foot grey cable)
   - Insert the TRACER’s battery or remove the battery and connect the A/C power adaptor provided to the base of the instrument.
   - Place the TRACER in the instrument stand.
   - Turn the power key to the “On” position.
   - Place the sample on the instrument (covering IR sensor) (Make sure that sample is flush on the face of the instrument with no gaps and that it is centered on the aperture.)
   - Select the correct Com Port from the “Download” menu.
   - The baud rate for TRACER III-V is 57600; for TRACER III-Vs it is 115200.
   - Select the “Setup” Menu and make sure the settings are as follows:



Select the Green button to activate Communications with the TRACER.

The yellow radiation warning window will open To close warning, simply click anywhere in the yellow window.

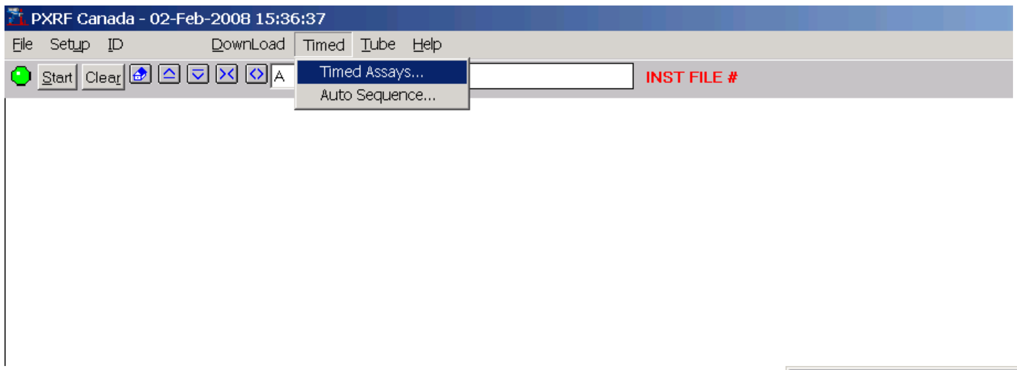


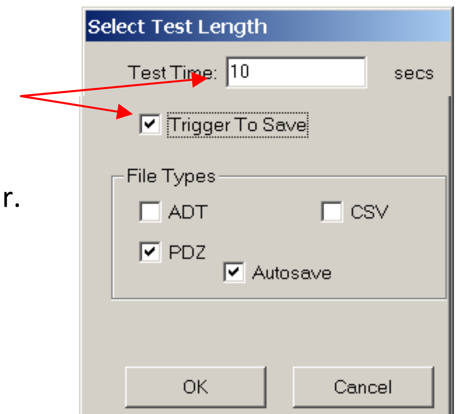
- Select **"Start"** in the PXRF window. (Within 2-3 seconds, you should see a spectra grow.) For optimum resolution, take at least a 30 second assay.
- Pull the instrument trigger.
- Click on "Stop".
- With the trigger pulled, select "Tube" from the menu and "KTI Tube/Read". Make sure that the Tube voltage, current and filter settings are appropriate for the sample of interest. (See Page 6.)
- Take spectra of first sample and label element peaks using the **"ID"** and **"Elem"** tools.

For first time users, it may be easiest to use the Duplex 2205 alloy sample that comes with each instrument. Your spectra should look like the one below. The first peak is the Chromium (Cr-K-shell), the second is the Iron (Fe-K-shell) and the third small peak is the Molybdenum (Mo-K-shell). Note that the Element ID window allow you to select K, L or M shell ID. You will want your KeyMaster periodic chart handy to help identify the K and L-shell energies. For a correct peak ID, the yellow lines should line up perfectly in the center of each peak. There will be alpha and beta lines for each element.

- *(If this is an alloy sample, you might skip this step and assume homogeneity).*

Take at least 3 assays from various locations on the sample to determine basic homogeneity of the sample

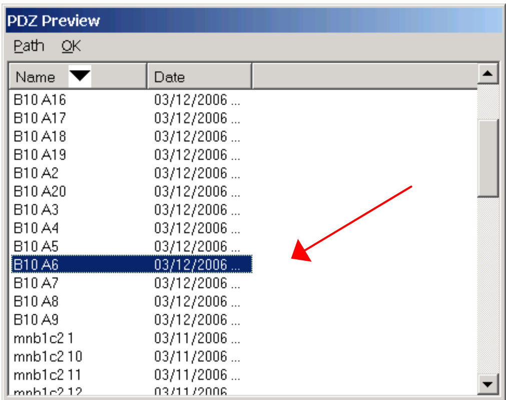




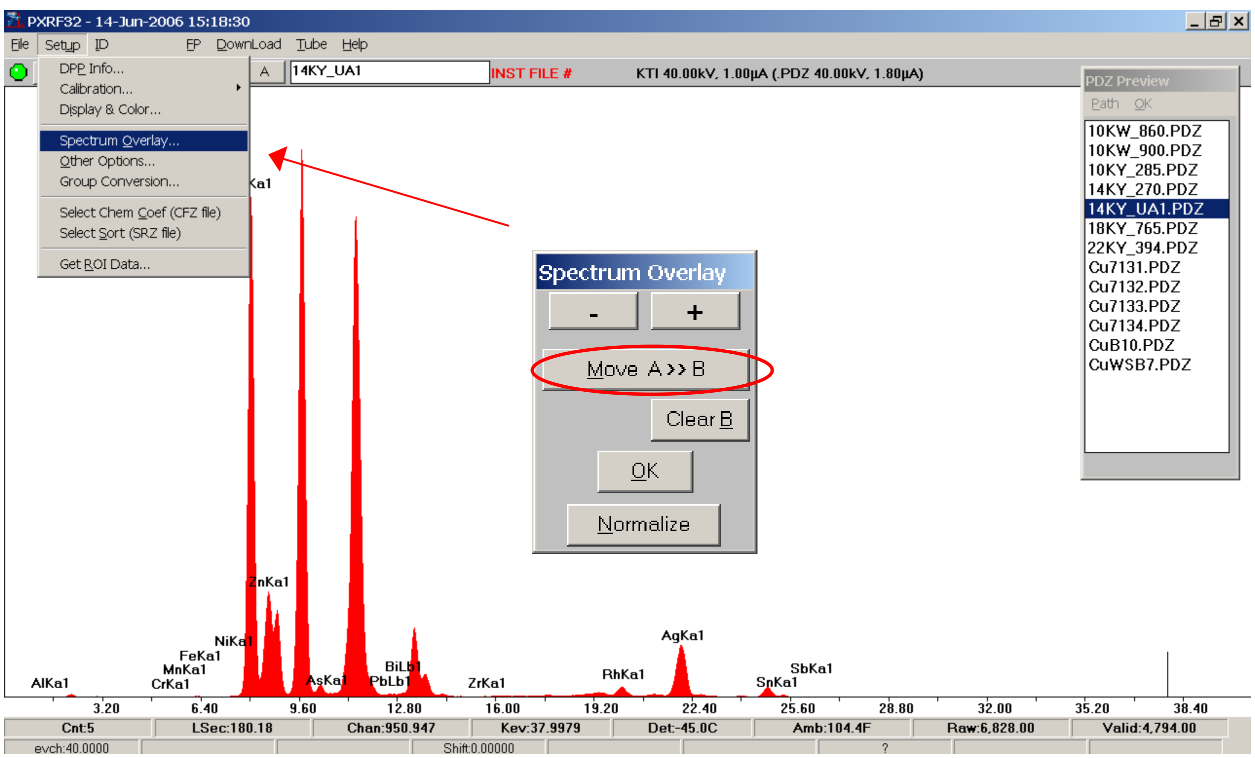
2. Take Timed Assays for each sample.
   - Go to the **"Download"** button on the PXRF Menu Bar.
   - Click on **"Auto Sequence"**. ("Back to Back" is for precision/accuracy testing.
   - Fill in **"Test Time"** (at least 60 seconds) and
   - **"Trigger to Save"** check the ".pdz", and "autosave".
   - Click **"OK"**.
   - Name the file to save the first sample assay.
   - Give the sample a name with no more than 5 characters and no spaces.
   - Click on the "**Start"** button.
   - Place the sample on the instrument.
   - Pull the trigger on the TRACER instrument to produce x-rays and spectral data.
   - Click on the **"Start"** button.
   - **Be sure to release the trigger between samples**.
   - Repeat for all the remaining samples
   - It is recommended to keep a record of the order in which the samples were scanned. (The program will auto increment the file names—001, 002, etc.

Reviewing Spectra

It is recommended that a new data folder be created for each new sample matrix and/or new instrument parameters, (e.g. new voltage or current, new beam filter, etc.)
To view and compare a sample group, select "PDZ Preview" from the PXRF "File" menu. Then click on "Path" and browse to the desired data folder. You can then index the files by name or date by clicking on the desired menu bar.



Spectra Overlays



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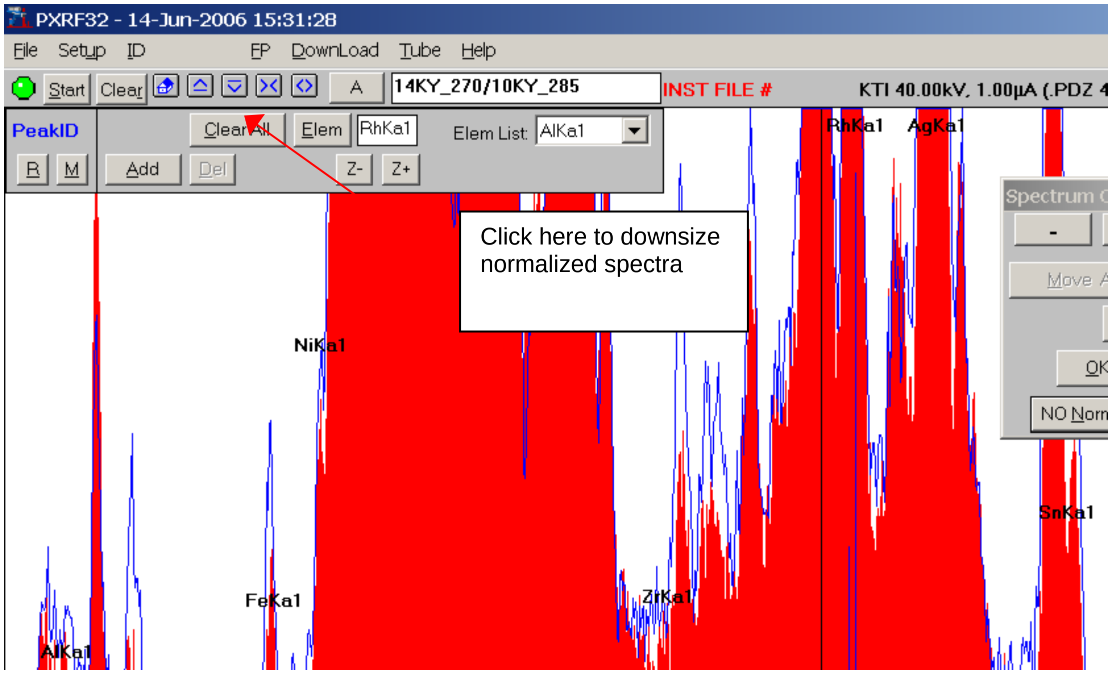
1. Open first spectra (".pdz" file)
2. Go to the "Setup" menu.
3. Select **"Spectra Overlay"**
4. Select **"Move A>>B**". This will put the first spectra in the background ("Spectrum B" in blue).
5. Select & open second spectra to overlay the first (This becomes "Spectrum A" in red).

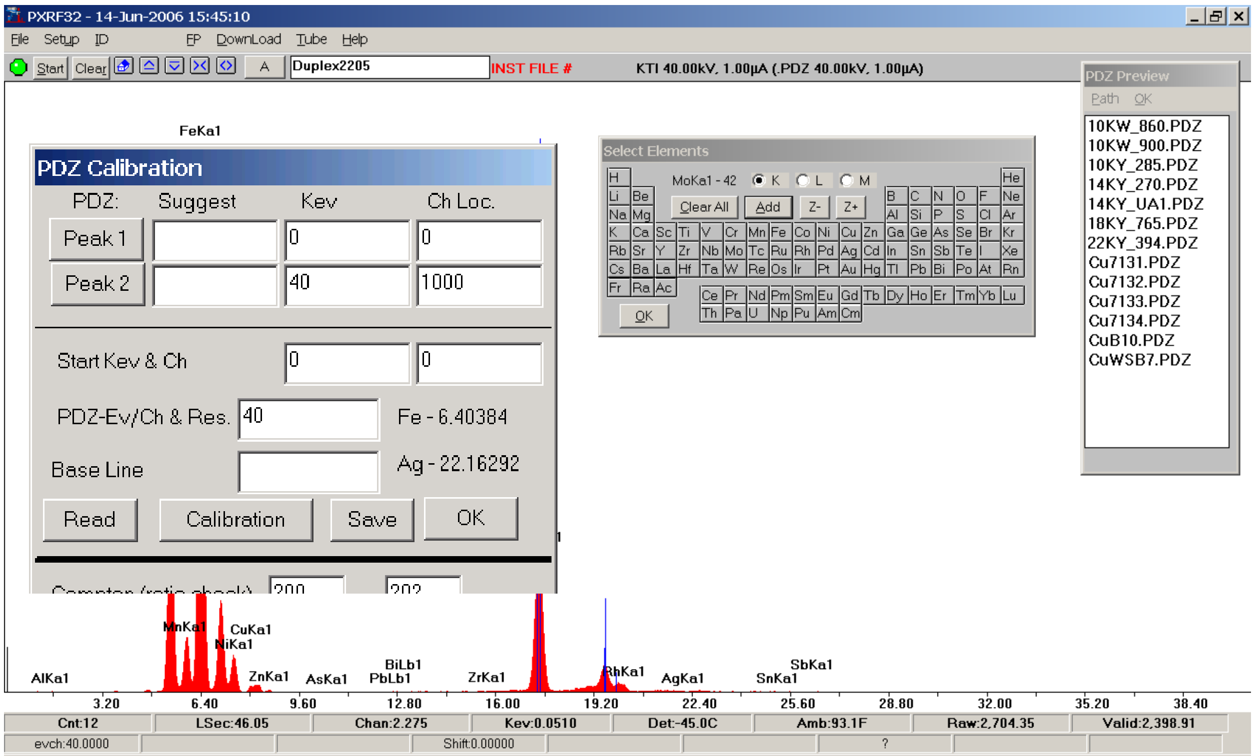
If matrixes or assay time is different, you can normalize on the Compton peak. e.g., For Rhodium target systems, place the black cursor at ~19.28kV and click on "Normalize".



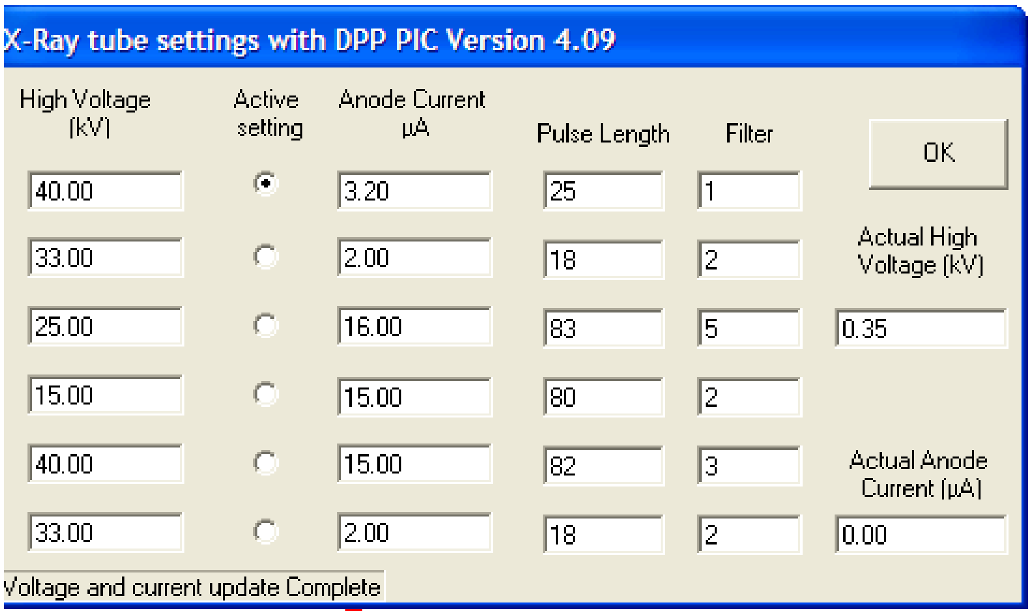
Quantification

1. **Open** "PXRF"
2. **Go to the** "Setup" **menu and** "Select Chem Coef"
3. **Select appropriate calibration file,** (".cfz") **file for the sample (Note: "Non-vac" vs. Al vac denotes Non-vacuum vs. vacuum calibrations and are stored in separate folders. Calibration files are named for their matrix, (Fe2, Cu1, etc.)**
4. **Now select a spectra file,** "pdz" **or use live data spectra.**
5. **Select** "Conc" (Concentration), This provides quantification of the elemental concentrations.

Creating a "PMIDefault.pdz" file (Energy Calibration)



1. Place the Duplex 2205 sample provided on the instrument.
2. Click on **"Setup"** then **"PPD calib"**…to bring up the PPD Calibration window shown above.
3. Pull the trigger on the TRACER.
4. Click on the **"Start"** button in the main PXRF window.
5. In the "Calibration" window, enter "0" in the Peak 1 "KeV" space and "0" in the Ch Loc.
6. In the "Calibration" window, enter "40" in the Peak 2 "KeV" space and "1000" in the Channel.
7. Click on "Calibration" button, then "Save" (The PDZ Ev/Ch should be "40" for the TRACER III-V.
8. On the **"File"** menu select **"Save (CE)"** and save the file as **"pmidefault"**.



The current setting, (µA) may vary slightly from instrument to instrument. However the settings above are typical.
The factory calibrations use the following settings:

Calibration Group	Voltage	Current Range	Filter
Non-Vacuum	40kV	1 - 4µA	1 (Al-300um/Ti-25um)
Iron			
Cobalt			
Nickel			
Copper (Bronzes)			
Gold			
Vacuum Titanium	33-kV	2-3µA	2 (Blank-No filter)
Vacuum Aluminum	15kV	15µA	2 (Blank-No filter)

When the energy of elements of interest change significantly, or the substrate density changes, you may need to change the voltage and/or current of the instrument. For example—if you would like to examine Cr and Ti only, (especially in low concentrations), you may want to set the voltage to “9.95” (These are considered low energy or low “Z” elements). For low density substrates, the current should be higher, for high density substrates, the current should be lower. (The total raw/valid count ratio should ideally be less than 3/2 and definitely less than 2/1.)